J. S. Newsom
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HISTORY OF GEOLOGY AND PALÆONTOLOGY

Karl v. Zittel

HISTORY OF GEOLOGY AND PALÆONTOLOGY

TO THE END OF THE NINETEENTH CENTURY

BY

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WITH THIRTEEN PORTRAITS

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PREFACE.

THE *History of Geology and Palæontology* was originally entrusted to Julius Ewald of Berlin. The Historical Commission of the Bavarian Royal Academy of Sciences could not have made a happier choice. Ewald was one of the few geologists who had been actively engaged in geological research during the first half of the nineteenth century; he had witnessed the most brilliant period of the rise of geology in Germany, and had been for a long time personally acquainted with most of the great exponents of the science on the Continent. Unfortunately it was not granted to Ewald to bring his task to completion. A few years before his death his feeble health compelled him to give up the work he had undertaken, and the results of many years' labour which he had expended upon it were entirely lost, as his will directed that all his unfinished manuscripts should be destroyed.

Although the present author of the *History of Geology* was asked to depict chiefly the history of the growth of the science in Germany, the nature of the subject is such that it could not be successfully treated along national lines. All civilised nations have shared in the development of the natural sciences, the history of any one of which must be to a certain extent the history of a scientific freemasonry. The questions of the highest import in Geology and Palæontology are in no way affected by political frontiers, and the contributions to the

progress of these studies made by members of any nationality can only be appreciated in their true values when held in the balance with the general position of research at the time, and with the discoveries and advances made by other geologists irrespective of nationality.

In spite of some doubt and consideration on my part, it seemed absolutely necessary to continue the *History of Geology and Palæontology* to the present day. A historical exposition of these sciences which should close with the sixth or even the eighth decade of the nineteenth century, would be out of date in many respects and out of touch with the modern standpoint. My task was made more difficult by such an extension of the subject-matter, as there has been no previous historical work dealing with the newer researches. Further, the mode of treatment which appeared most suitable for the older periods could not be retained with advantage for the treatment of the modern development. The greater and greater specialisation and branching of the science which took place during the latter half of the nineteenth century, seemed to demand individual descriptions of the different areas of research in preference to a general comprehensive survey of the leading features in all.

The geological writings of antiquity have little scientific value, and they are therefore only briefly indicated. Again, the period subsequent to the downfall of the Roman Empire and extending into the second half of the eighteenth century, though it has contributed a number of noteworthy observations, is mainly conspicuous for its hypotheses. Whewell, Brocchi, Lyell, and others have depicted this older development of geology. Keferstein's *Geschichte und Literatur der Geognosie* is continued to the year 1840, but for the period from 1820 to 1840 it supplies only an enumeration of books

and memoirs. Friedrich Hoffmann gave a much more attractive account of the history of geology, and carried it as far as the year 1835. The history of geology by Sainte-Claire Deville covers practically the same ground, but devotes more than a third of the whole work to the writings of Élie de Beaumont. The eight volumes of D'Archiac's *Histoire des Progrès de la Géologie* provide for the period 1834 to 1850, afterwards continued to 1859, an exhaustive discussion of all the geological publications that appeared during this time, but is a work intended primarily for the specialist. The chief work and the later historical writings of this eminent Frenchman gave the predominant place to French authors, and owing to his defective knowledge of German, the contributions in that language met with scant attention. H. Vogelsang's *Philosophie der Geologie* contains an interesting, but very subjective, historical introduction, wherein the progress of petrographical knowledge is more especially considered. Valuable contributions to the history of geology have been made by the fluent pen of Sir Archibald Geikie. His admirable biographies of Sir Roderick Murchison and Sir Andrew Ramsay offer far more than the title indicates. With unsurpassed literary skill and scientific mastery of the subject, they describe the development of geology in Great Britain during the lives of these illustrious geologists. In a course of lectures on the *Founders of Geology*, Sir Archibald Geikie has given a series of admirable biographies from which may be culled a connected account of the early advances in the science of geology.

I have derived information from all the above-mentioned works; but it has usually been my endeavour to consult the original sources, and to form my own judgment independently of all books of reference. Where critical treatment was called

for, I have tried to preserve the strictest impartiality; in the case of controversial matters which have already arrived at a solution, I have limited myself to the objective attitude of the historian.

The original works of reference are cited at the conclusion of each chapter, and will prove useful to the more special student of the subject.

Whether I have succeeded in the difficult task of writing a History of Geology and Palæontology that will satisfy the specialist and also commend itself to every man of culture, must be left for my readers to decide.

KARL A. VON ZITTEL.

MUNICH, *June* 1899.

TRANSLATOR'S NOTE.

THE text of the original has been somewhat curtailed in the translation, both in order to meet the wish of the author, and to secure uniformity with the other volumes of the Contemporary Science Series. I have omitted entirely a chapter of seventy-seven pages on Topographical Geology, which was more special in character than any of the other chapters. I have also omitted the lists of books of reference, taking care to embody in the text all the more important publications; and have condensed the subject matter wherever it seemed possible to do so without detracting from the scientific value of the *History*. These changes have been made with the author's approval. It only remains to add that, as a former pupil of Geheimrath Professor von Zittel's, and one who bears very grateful feelings towards him, it has afforded me great pleasure to translate this work.

MARIA M. OGILVIE-GORDON.

ABERDEEN, *October* 1901.

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,,	170,	,,	22,	,,	"Julius Roth,"	,,	"Justus."
,,	208,	,,	6,	,,	"Eber,"	,,	"Ebel."
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HISTORY OF GEOLOGY AND PALÆONTOLOGY.

INTRODUCTION.

First Period—Geological Knowledge in the Ages of Antiquity.

In all ages there have been men who have given serious thought to the historical aspect of our terrestrial home, to its origin and its development; but any clear conception of the beginning of the Earth—based, that is, upon scientific facts—was as remote from the most cultured nations of antiquity as it is at the present day from the barbarous races of mankind. The polymorphous myths of the Creation represent the varying ideas which were formed regarding natural phenomena; the limit of the spiritual field of vision determined the wider or more circumscribed flights of imagination. The wide chasm between the childish Saga of Creation handed down by the Bushmen, Australians, Eskimos and Negroes, and the grand poetic conceptions of the Aryan-Germanic races of Europe, conveys to us the immense difference at that time in the condition of culture and intellectual capacity of these peoples.

Tradition has preserved to us the cosmogenetic and geogenetic views of the civilised races of the Mediterranean countries and of Asia, and these arouse our admiration by their poetry and philosophic depth. But there was no trace either of exact observation of natural phenomena, or of logical deduction from such observations.

Amongst the ancient stories of the Creation the Babylonian and Jewish accounts are pre-eminent for their intuitive skill and for the excellence and conciseness of their language. The

traditions of the Babylonians are recorded in the cuneiform inscriptions found in the ruins of Nineveh. Creation begins with Chaos. The gods arose before heaven and earth had taken shape, while the tumultuous floods of oceans were still intermingled in the universal chaos. The gods chose Marduk to be their champion against Tiamat, the disturbing, chaotic ocean-flood. Marduk armed himself with lightning flash and thunderbolt, and called the winds to his assistance. Marduk vanquished Tiamat, and divided his corpse into two parts; from the one part he created the heavens, and from the other the earth and the sea. Marduk peopled the heavens with stars, the dwellings of the great gods. Then followed the creation of plants and animals, and finally the creation of the two first human beings out of clay. The evident agreement of the Babylonian and Jewish conceptions becomes even more apparent in the account of the Deluge, which was at first only known to us from the epic of Berosus, but has now also been discovered in cuneiform inscriptions.

The Mosaic account of the Creation far excels the Babylonian in its noble simplicity and in the strength and beauty of the language. In it the origin of the world, of the earth and its inhabitants, is represented as the work of a personal Almighty God. The Jews were alone among the great nations of antiquity in realising the godhead as a unity—all-powerful, all-embracing. The Mosaic account was incorporated in the Bible of the Christian Church, and, unfortunately, became invested with a scientific value by the Church. This retarded the development of geology for many centuries, inasmuch as theologians regarded the Mosaic account as a divine revelation, an essential dogma of the Christian Church, and sought to suppress any investigations and writings of scientific interest which did not harmonise with it.

While certain natural events, such as earthquakes, floods, and sometimes volcanic eruptions, recur in the primitive traditions of the different nations, these cannot be regarded as affording a basis of geological facts; their interest is rather mythological and religious than scientific.

The Greeks were less inclined than the Oriental nations to interweave the ideas of mythology, religion, and science; they viewed natural events from a more critical standpoint, and treated them as subjects of philosophical speculation. Various hypotheses were formed to explain the beginning of the earth.

Hesiod's "Theogony" is the oldest of the Greek cosmogonies, but from what we know of it, the speculations of this early Greek philosopher were rather brilliant flights of fancy than efforts to assimilate observations of natural phenomena. Thus, the world is said to have taken origin from a primeval chaos, and to have given birth to the heavens, the mountains, and the oceans; then the races of gods sprang from the earth and the heavens.

Thales of Miletus, the contemporary of Crœsus and Cyrus, considered that everything, animate and inanimate, was derived from water. His gifted scholar, Anaximander (born *circa* 611 B.C.), arrived at a higher conception of Nature. He depicted an infinite, all-pervading primeval substance, possessing an inherent power of movement from the first. The energy of this primeval matter determined heat and cold, and the mixture of these conditions gave origin to the development of fluid; the earth, the air, and a surrounding circle of fire differentiated from the fluid state. The stars sprang from fire and air; the earth rested in the centre of the whole universe, and under the influence of the sun brought forth the animals which inhabit it. These, including human beings, were at first fish-like in form, consistent with the semi-fluid state of their environment. Thus Anaximander had the merit of appreciating certain physical states as attributes of universal matter; his work, περὶ φύσεως, is unfortunately lost.

Xenophanes of Colophon (born 614 B.C.) is reported by later writers to have observed the shell remains of pelagic mollusca on mountains in the middle of the land, impressions of laurel leaves in the rocks of Paros, as well as various evidences of the former presence of the sea on the ground of Malta, and to have attributed those appearances to periodic invasions of the sea during which men and their dwellings must have been submerged. The historian Xanthus of Sardis (*circa* 500 B.C.) also drew attention to the occurrence of fossil shells in Armenia, Phrygia, and Lydia, far from the sea, and concluded that the localities where such remains occur had been formerly the bed of the ocean, and that the limits of the dry land and the ocean were constantly undergoing change.

Herodotus (born 484 B.C.) mentioned the presence of fossil shells of marine bivalves in the mountains of Egypt and near the oasis of Ammon. From this fact, as well as from the salt constitution of the rocks, Herodotus formed the opinion that

Lower Egypt had been at one time covered by the sea, and that the material carried down by the Nile had been discharged into the sea-basin between Thebes and Memphis and the present delta, and gradually filled it up. Herodotus could not form any definite opinion as to the cause of the Nile inundations, although he gave a careful report of the hypotheses then in favour.

Heraclitus (born 535 B.C.) thought there was in the universe nothing stable, nothing lasting. Everything was in a state of constant change, like a stream in which new waves endlessly supplant the old. For him fire was the primeval force, which unceasingly transformed itself, pervaded every portion of the universe, produced individuals, and again destroyed them. Fire became the ocean, and that again earth, and the breath of life. The rising vapours burned in the air and formed the sun, which was renewed from day to day. Thus Heraclitus taught that although the universe always had been and always would be, no portion of it had ever been quiescent, and that from time to time a new world was constructed out of the old.

Pythagoras, who was born at Samos about the year 582 B.C., and afterwards went to Crotona in Italy, is one of those eminent leaders of thought around whose name and teaching much that is mythical has gathered. The exponents of his teaching in subsequent ages too often attributed to the early Pythagoreans conceptions which were in reality foreign to the doctrines of the great master himself, and it is extremely difficult to disentangle the threads of original thought from the confused web of tradition. It is clear that the Pythagoreans indulged more in abstract speculation than their predecessors, and gave less attention to observation of nature. They sought to explain natural phenomena chiefly by analogy with definite numerical relationships. An ordered universe depended, according to the Pythagoreans, upon the principle of numbers. Consequently the properties of numbers, individually considered, in sequence, and in combination, were investigated with a zeal which enabled the school to lay the foundation of important mathematical advances. In applying the principle of numbers to musical sound, Pythagoras is reputed to have arrived at a true conception of musical intervals and to have established the theory of the octave. On the other hand, the Pythagoreans were less happy in their application of the limita-

tion of numbers to the physical problems of the universe, and lost themselves in forced analogies and conjecture regarding the "harmony of the spheres." According to Diogenes Laertius, Pythagoras imagined the universe in the form of a sphere. The earth was in the centre, and bore the axis around which the firmament revolved. The moon, the sun, Mercury, Venus, Mars, Jupiter, and Saturn described circular paths round the earth, and the harmonic motion of these bodies called forth the music of the spheres. The Pythagorean Philolaus improved on this conception. He described the universe as a system comprising ten heavenly bodies—the five planets, the sun, the moon, the earth, and a counter-earth which moved from west to east round a "central-fire." The earth turned one half towards the central-fire, whilst the other, or inhabited half, received light and heat from the sun. Entirely beyond the circles of this system lay the fixed stars and the illimitable ether from which the universe drew its breath.

The principle of constant change taught by Pythagoras and Heraclitus is also a leading feature in the doctrines of Empedocles of Agrigentum (492-432 B.C.). Empedocles supposed that everything had its origin in, and took its components from, four elements (earth, water, air, and fire); that these elements were without beginning and imperishable, but subject to never-ending change. From these elements the world at one time took shape, and it must at some future time be again dispersed. The course of the world's existence resolved itself into a history of recurring periods and phases. As Empedocles did not concern himself about an empirical basis for most of his theories, it is of little avail to enter into his physical and biological speculations. Geology, however, owes one distinct step in advance to this philosopher. Whereas the Pythagoreans had conjectured the presence of a central fire in the universe, Empedocles taught that the earth's centre was composed of molten material. Empedocles formed this opinion on the basis of his actual observation of the volcanic activities of Mount Etna. Tradition says that he met his death by falling into the crater of that volcano.

Leucippus and Democritus of Abdera (*circa* 490 B.C.) were the founders of the school of atomic philosophy, which of all the Greek systems approaches most nearly to the opinions of the present day. According to Democritus, the only realities

are atoms; nothing that exists can be destroyed; change takes place in virtue of the combination or separation of atoms. Atoms are always in motion and are endless in number and variety; they move about in space; they press upon one another in every direction; they assume eddying movements which give origin to new worlds: but everything happens according to a definite sequence of law, and nothing by chance. Even the soul consists of very finely divided atoms which permeate the body and call forth the phenomena of life.

In opposition to the materialistic view of the atomic philosophy, Anaxagoras of Clazomenæ (born 501 B.C.) regarded the soul (νοῦς) as in itself a conscious, moving force. In his cosmic philosophy he supposes an original chaos in which a circular movement gives place to a universe, and at the same time effects a differentiation of ether, air, and water. The earth rises from the water, and receives seeds from the air which develop into living plants and animals. The earth is poised as a cylinder in the centre of the whole universe, and the stars move round it.

As the influence of the Sophists and Platonic philosophy came more into ascendency, it tended to elevate dialectic and speculative methods and to depreciate the investigation of natural phenomena. Cultivated and gifted as the Athenians of this epoch were, natural science owes but a small debt to them.

Plato (427 B.C.), in his Cosmology, is a follower partly of Heraclitus and partly of Anaxagoras. According to Plato, the universe is the production of divine intelligence and of the necessary development of nature. The form of the whole universe is spherical; in the centre lies the earth as a motionless sphere; around it are the sun and the planets, and the fixed stars occupy the outermost circle. All the heavenly bodies are inhabited; the atoms composing them are indivisible, and unite along definite limiting surfaces; the universe itself is unchangeable and indestructible.

An interesting account is given in the "Timæus" of a submerged Atlantic continent (Atlantis) on the other side of the Pillars of Hercules (Gibraltar). The idea of such a submerged continent has again received credence in recent geological researches. In Plato's account Atlantis was larger than Asia and Libya together, it had been inhabited 9000 years

before his time, and since its destruction by earthquakes and inundations navigation in the Atlantic had been impossible owing to the fine mud and detritus left by the vanished land.

The work of Aristotle (384-322 B.C.) marks the culminating point reached by the Greeks, both in the domain of speculative philosophy and in that of empirical observation. Although the physical and geological researches of the great Stagirite embrace less of original discovery than his researches in zoology and physiology, they group and define more precisely the best results of the Eleatic, Pythagorean, and Atomic philosophers, re-animate them with new thoughts, and frequently place them on a true scientific basis. Aristotle departs from the atomic philosophers in assuming that matter is diverse in quality, and that the universe is divided into an earthly and a heavenly half; the imperishable ether belongs to the heavenly half, while the four elements, earth, water, air, and fire, compose the earth and the planets. The earth forms, in Aristotle's conception, the stationary centre of the universe round which the planets move to the left; beyond their orbits is the great ethereal circle of the heavens in which the stars move towards the right. The development of the earth is comparable with that of an organism; it has periods of growth, maturity, and decay. During recurring periods of rejuvenescence the lower animals take origin in the mud of the earth, and from them develop, by sexual generation, the higher groups of animals. The plants are related to animals, and the different kinds of animals to one another by numerous transitional forms. Aristotle's works seldom treat special geological questions, and his meteorology, although it discusses earthquakes, the alternation of continent and ocean, the Deucalion flood and inundations of the Nile, does not contribute much that is new.

Theophrastus of Lesbos (368-284 B.C.), the most famous pupil of Aristotle, devoted himself chiefly to scientific studies. In addition to his valuable botanical treatises, he gave much information about minerals and fossils in a fragmentary treatise "On Stones." A special work on fossils, with which Pliny was apparently acquainted, has since been lost.

The Encyclopædists of the Alexandrine school occupied themselves chiefly with astronomy, mathematics, and geography. Eratosthenes (276-196 B.C.) by his measurement of the degree in Egypt for the first time laid the foundation of a more exact estimate of the size of our planet. He

also gave expression to various hypotheses regarding the relationship of mountain-chains, the action of water, and the presence of the ocean above the continent, as indicated by the occurrence of oysters and other marine organisms in the Libyan deserts on the way to the oasis of Ammon. Eratosthenes taught that the changes of form accomplished by means of water, by volcanoes and earthquakes, and by fluctuations of the sea, are insignificant in proportion to the size of the whole earth.

Thus it will be seen that the majority of the older Hellenic philosophers gave their attention to speculative considerations on the origin of the universe and the earth; but under the manifold activities of the Roman empire, a new and more realistic spirit became infused into the investigations of the great thinkers. Amongst these the first place must be given to the historian and traveller Strabo (born *circa* 63 B.C.), whose geography, comprising seventeen volumes, was written about the beginning of the reign of Tiberius. Strabo had a thorough mastery of the Greek literature, and in reference to the occurrence of the above-mentioned fossils in the Libyan desert, he agreed with the Greek philosophers that the sea had once covered certain portions of the land, but he also pointed out that the same district may sometimes rise, sometimes sink, and fluctuations of the sea-level are associated with such movements of land-surfaces. He further taught that elevations and subsidences of the land are not confined to individual rocks or islands, but may affect whole continents; that Sicily, Procida, Capri, Leucosia, the Sirenian and Œnotrian islands had been separated from Italy by earthquakes, and that probably all islands off the shores of continents had originally formed part of the mainland. The oceanic islands far from any mainland have, according to Strabo, been thrown up by subterranean fires. In support of this view Strabo cited the case of a volcanic eruption in the year 196 B.C. between Thera and Therasia. For four days flames rose from the ocean, and as these died down it was observed that a new island had been formed, measuring twelve stadia in circumference. Again, near Methone in the Hermionian Sea, a mountain, seven stadia high, had been thrown up during outbursts of sulphurous vapours and fire; and the town of Spina, near Ravenna, formerly a seaport, was now ninety stadia inland. Strabo is therefore rightly regarded as the father of modern

theories of mountain-making, and we owe to him, moreover, the hypothesis that volcanic outbursts act as safety-valves for the pent-up activities of subterranean vapours. He pointed out, that Sicily in his time was less frequently disturbed by earthquakes than it had been in previous ages before volcanic discharges were known in the district, and he correlated the comparative tranquillity of the ground with the means of escape afforded for explosive underground vapours by the volcanic vents that had opened at Etna, in the Lipari Isles, and in Ischia. It speaks highly for Strabo's powers of observation that he should have recognised in Vesuvius a volcanic mountain although it was then quiescent.

Probably the most acute scientific observer of Roman times was Seneca, the physician of the Emperor Nero (born 2 or 4 B.C., died 65 A.D.). Quite recently, Nehring has placed the importance of the work of Seneca in its true light. The *Quæstiones Naturales* contain detailed communications about earthquakes, volcanoes, and the constructive and destructive agencies of water. Seneca explains earthquakes partly as a result of the expansion of gases accumulated in the earth, partly by the collapse of subterranean cavities. He regards volcanic eruptions simply as an intensified form of the same series of phenomena, and volcanoes themselves as canals or vents between local sub-terrestrial reservoirs of molten material and the earth's surface. He names the chief volcanoes, placing Etna in the first rank; then Stromboli, Therasia, and Thera (the present "Santorin"), but there is no mention of Vesuvius. He regards the earth as primitively a watery chaos, and it is more especially in his treatment of the action of water in dissolving and carrying away rock-material, together with his explanation of the origin of sediments and deltas, that Seneca has shown his remarkable insight and sound judgment.

The learned historian, Pliny the Elder (23-79 A.D.), has handed down to us a compendium that embraces the whole scientific knowledge of antiquity. His *Historia Naturalis*, in thirty-seven books, embraces the natural history of animals, plants, and stones, the history of the heavens and the earth, of medicine, of commerce, of navigation, etc.; in Lib. II., c. 88 and 89, all the islands that have been thrown up in the ocean are enumerated—Delos, Rhodes, Anaphe, Nea, Alone, Thera, Therasia, Hiera, Automate, and Thia. The reports

about volcanoes, earthquakes, and fossils, occurring here and there in this work, are not always trustworthy. They seem, in most cases, to have been based on indirect information. By a tragic decree of fate, the untiring student and naturalist met his death while engaged in observing the grandest geological event of antiquity, the first outbreak of Vesuvius in the year 79 A.D. Pliny the Younger describes the death of his uncle in two letters to Tacitus, recounting how at the beginning of the eruption the elder Pliny was stationed at Misenum as Commander of the Fleet, but went at once to Stabia to bring help to the sufferers and to witness the great drama of nature. He died in the open field, probably suffocated by the volcanic vapour and ash. His corpse was found unharmed three days later, when the darkened sky gradually became clear. The younger Pliny's vivid description of the eruption of Mount Vesuvius, and the accompanying earthquake, is one of the most remarkable literary productions in the domain of geology. It is certainly curious that he should have omitted to mention the earth-tremors at Herculaneum, Pompeii, and Stabia, confirmation of which has however been given by Dio Cassius.

A poetic account of an eruption of Mount Etna is happily amongst the fragments that have been preserved from the works of Lucilius, the poet in the second century A.D. Altogether this volcano played a very important *rôle* in the literature of the ancient writers. Nor were the Romans devoid of interest in fossils: Suetonius relates that the Emperor Augustus decorated his villa in Capri with huge fossil bones, which at that time were held to be the remains of a giant race.

If we pass in review what antiquity has bequeathed to us of actual geological knowledge, we find our heritage surprisingly meagre. The tendency of eastern races towards the fanciful, and of the Greeks to philosophical speculations, brought forth an abundance of hypotheses about the origin of the universe and the development of the earth; and even although some of these may in part coincide with accepted scientific conceptions of the present day, it has to be remembered that in these cases the early hypotheses were rather happy "guesses at truth," than general theories founded inductively upon a series of accurately observed data.

Far more valuable than the most ingenious speculations are

the occasional remarks and observations about volcanoes, earthquakes, fluctuations of level in the land-surfaces, the action of water, and other phenomena of dynamic geology, as well as the scattered notes about the occurrence of fossils. On the other hand, not a single writer of the ancient world showed any interest in the firm earth-crust, not one observer gave a thought to the composition of the rocks. Not the most acute thinker of those cultured peoples had even a shadowy premonition of the value that might appertain to fossils as witnesses of a sequence of events in the history of our earth. None suggested that our planet might have passed through a succession of changes before attaining to its present physical condition and configuration; still less, that particular phases in the history of change might be deciphered from the character and superposition of the rocks. The evolution of the earth and its denizens, which is at the present day the great problem of geological and biological research, played no part in the literature of antiquity; fanciful hypotheses and disconnected observations cannot be acknowledged as scientific beginnings of research.

SECOND PERIOD—THE BEGINNINGS OF PALÆONTOLOGY AND GEOLOGY.

The downfall of the Roman Empire dealt a severe blow to literary progress and healthful interest in natural phenomena. The collapse of imperial power, the revolutionary instincts and unrest, the variable migration of the races, the protracted struggle between decaying heathendom and rising Christianity, the personal wars of jealousy and greed in which Europe was plunged during the greater part of the Middle Ages, all combined to check any spontaneous desire towards scientific investigation.

A barren scholasticism took refuge in the monasteries and cloister schools. The attitude of the Schoolmen, while it made much of logical distinctions and the critical interpretation of old doctrines, was unfavourable to the direct observation of nature. For many centuries (800-1300 A.D.) the Arabs were the only nation in which the true spirit of ancient culture and inquiry was kept alive. At great sacrifice they obtained possession of the classical works of antiquity, translated them

into Arabic; and the Caliphs, Al Mansur, Harûn-al-Raschid, and Al Mamûn, endeavoured to attract to their courts the best scholars of all countries. Thus they handed down to posterity many of the most valued treasures of ancient learning, and they appreciably contributed to the knowledge of mathematics, astronomy, alchemy, medicine, and zoology. Geology and palæontology, however, the kindred studies of the rocks and their fossil contents, were almost neglected by them.

It was not until the close of the Middle Ages, in the fifteenth century, that a revival of learning spread through Europe. The discovery of the art of printing brought books within the reach of many. The keen interest in classical authors displayed by the leaders of the Humanist movement infused new life and activity into mental effort in every branch of knowledge. Universities, learned societies, and academies were founded.[1] The methods of dogmatism were cast aside with the decay of scholasticism. Copernicus the Prussian (1473-1543) absorbed the best learning that Italy could give him, and rewarded the care of his foster-country by unfolding to futurity the system of the universe that bears his name. The Reformation gave an impulse to all men to think for themselves, and no longer to accept blindly the traditions of past ages. Columbus, Vasco da Gama, and other bold navigators added the Western Hemisphere to the former domain of geographical knowledge. And if less imposing, still no less certain, was the steady advance made in natural science under the influence of the healthier tone that prevailed. Men turned in earnest from

[1] Italy led the way in founding academies during the era of the Renaissance of literature and research. The "Platonic Academy" was the name given to a group of learned men who were under the patronage of Cosmo di Medici, in Florence; but this society had no definite organisation. The Academy in Padua, founded in 1520, must therefore be regarded as the oldest scientific society, although it was not long in existence. In 1560 an Academy of Natural Science was founded at Naples, and in 1590 the Academy dei Lincei in Rome was founded by the Marcese de Monticelli. It was not until the middle of the seventeenth century that the scientific academies of France, England, and Germany came into existence; then were established the Académie Française in 1633, the Royal Society of London in 1645 (established in 1662 with incorporated rights), the Académie des Sciences in Paris in 1666, and the Akademie der Wissenschaften in Berlin in 1700. In 1725, Empress Catherine founded the Academy in St. Petersburg, and in the same year the Royal Society of Sciences was formed in Upsala. Since that time scientific societies have been founded in most of the large university towns.

the desultory literary method of treating nature, to the more direct, more exacting system of observation and description. Plants, animals, and rocks were studied with enthusiasm, were examined, described, figured, and classified, so that in a relatively short space of time a fairly extensive botanical, zoological, and mineralogical literature sprang into existence.

Various Opinions about Fossils.—The Greek and Roman writers had correctly realised that fossils represented the remains of animals and plants, and most of the ancient writers had explained their preservation in the rocks as the result of great natural catastrophes which had changed the localities of land and water, and brought the swarming denizens of the sea into the middle of continents, burying them there. During the mediæval Scholasticism no progress was made in the study of fossils. Avicenna (980-1037), the Arabian translator and commentator of Aristotle, became imbued with Aristotle's theory of the self-generation of living organisms, and tried to extend it to the case of fossils. Avicenna suggested that fossils had been brought forth in the bowels of the earth by virtue of that creative force (*vis plastica*) of nature which had continually striven to produce the organic out of the inorganic, and that fossils were unsuccessful attempts of nature, the form having been produced but no animal life bestowed.

The famous Albertus Magnus[1] takes the same standpoint more than two hundred years later. He assumes a *virtus formativa* in the earth as the origin of fossils, although he allows that the remains of plants and animals may be turned to stone in places where agencies of petrefaction are at work.

With the dawn of the fifteenth century began that long series of disputes about fossils which lasted more than three centuries. The questions under discussion were, whether fossil organisms had taken origin from a *vis plastica*, or from living seeds carried in vapours from the sea, or from any living force in the earth itself; whether they might be regarded merely as illusory sports

[1] Albert von Bollstædt, called Albertus Magnus, was born at Laningen in Swabia in 1193; studied at Padua and Bologna, took Dominican orders in 1222, lectured for several years in the cloister schools of Cologne, Hildesheim, Freiburg, and Regensburg, and taught in Paris between the years 1245-48. He returned then to preside over the High School at Cologne, and was made Bishop of Regensburg in 1260. This post he resigned after two years, and devoted himself, at Cologne, to his works on philosophical and theological themes until his death in 1280.

of nature, or as mineral forms, or if they really were the remains of animals and plants that had once lived, and had been brought by the Flood or some other catastrophe into their present position.

The world-famed artist and architect, Leonardo da Vinci (1452-1519), took part in the discussion. He had in his youth been engaged as an engineer in the construction of canals in North Italy, and had then seen numerous fossils in position in the rocks. The opinions he formed regarding them are remarkable for their clearness and correctness. Leonardo said that the marine organisms scattered in the earth in the form of fossils had actually lived where we now find them. The sea at that time covered the mountains of North Italy: the river-mud brought to the sea from Alpine lands filled the shells of dead mussels or snails, and accumulated on the sea-floor; afterwards the mud deposits became dry land, and the fossils found in them were the casts of the ancient cells. He ridiculed, as absurd and unscientific, the idea that such perfect models of living organisms could have taken origin in the rocks under hypothetical creative influences of the stars.

The Neapolitan, Alessandro degli Alessandri (1461-1523), mentions petrified conchylia in the Calabrian mountains, and ascribes their presence to an inundation of the continent by the ocean, caused by some exceptional catastrophe, or by a change in the axis of rotation of the earth.

Fracastoro,[1] in the year 1517, gave clear expression to his convictions about fossils, which were in accordance with those of Leonardo da Vinci. During the building of the citadel of San Felice in Verona, the workers found fossil mussels in the rocks and laid them before Fracastoro, begging him to explain the marvel. Fracastoro repudiated the doctrine of a *vis plastica* in the earth as impossible; and just as little did he give credence to the view that explained fossils as creatures left by the great Flood. The Flood, he said, was of short duration, and in the nature of things it would have left not marine but fresh-water mussels behind; further, on the assumption that the mussels had been carried from the ocean to the land by the Flood, their remains would have been scattered over the

[1] Hieronymus Fracastoro, born at Verona in 1483, studied at Padua, and became Professor of Philosophy there in 1502; afterwards practised medicine as a physician in Verona, and in his capacity of physician to Pope Paul III. was a member of the Council of Trent. He died in 1553.

surface of the land, and would not have been buried deep in the earth where the quarrymen had found them. There was left, he continued, only one possible explanation—that the fossils were the remains of animals which had once lived in the localities where their remains are now imbedded.

Far more illustrious than the majority of his contemporaries in science was George Bauer,[1] better known by his *nom-de-plume* of Agricola. Werner calls him the father of metallurgy, and the originator of the critical study of minerals. Bauer's stay in Joachimsthal enabled him to become familiar with the mines there, and to make a collection of local minerals. The clever physician soon received general recognition as the best authority on mining, and the publication of his pamphlet "Bermannus" in 1528 further confirmed the prominent position he held among mineralogists. His great work, *De re metallica libri duodecim*, contains a complete description of mining and metallurgy as then practised, as well as valuable communications about the mode of occurrence of useful minerals, and about veins and deposits of ore. Two later works, *De natura fossilium*, Lib. x., and *De veteribus et novis metallis*, Lib. ii., describe all the minerals known to the ancients, and all those which had since been discovered. Agricola's observations on crystalline form, cleavage, hardness, weight, colour, lustre, etc., have served as a model for all subsequent descriptions of minerals. On the other hand, Agricola's remarks about fossils are of much less value. He had devoted little attention to the fossil remains of animals and plants, and he unfortunately united under the name "Fossilia" both minerals and petrified organisms. This use of the term "Fossils" was perpetuated for two centuries in the literature, having been more especially adopted by the famous Wernerian School. Agricola referred by far the greater part of the organic remains found in the solid rock to a wholly inorganic origin; he regarded fossil mussels, belemnites, "Ammon's Horns," "Glossopetra" (fish teeth), and other problematical remains as

[1] Georg Bauer (Agricola) was born at Glauchau in Saxony in 1494. He went to Italy, where he graduated as doctor, and then settled in Joachimsthal as a physician; afterwards he was appointed professor of chemistry at Chemnitz, and died there 1555. A complete edition of his works was published in the Latin tongue in Bâle. A German translation of the mineralogical writings was published at Freiburg in 1816 by Ernst Lehmann.

"solidified accumulations from water," analogous with marble and limestone. Yet in the case of fossil leaves, wood, bones, and fish, Agricola allowed an organic origin, and thought the various objects had become petrified by the action of a certain *Succus lapidescens* everywhere present in water.

Conrad Gesner, the famous Zürich scholar, also formed no very definite opinion about fossils. To him we owe the first illustrated work on fossils, *De rerum fossilium, lapidum et gemmarum figuris*, which appeared at Zürich in 1565, the year of Gesner's death. He discusses the fossils along with other products of the soil (minerals, ores, prehistoric stone implements, stalactites, etc.), and compares some with the sun, moon, and stars, others with plants and animals, without entering further into their origin.

The zealous collector, Johann Kentmann, in Torgau, and the Würtemberg physician, Johannes Bauhin, made no further inquiry into the nature of fossils, but Bauhin described, and gave figures of a large number of ammonites, belemnites, mussels and brachiopods from the Posidonomya shales and Middle Lias strata in the neighbourhood of Boll.

In Italy, Andrea Mattioli, the botanist, described the fossil fishes of Monte Bolca for the first time in 1548, and followed Agricola in supposing that porous shells, bones, and other remains had been converted into stone by a *Succus lapideus*. Nearly ten years later, the anatomist Fallopio, in Padua, even went so far as to call the fossil teeth of elephants from Puglia earthy concretions, and fossil shells from Volterrano the results of fermentation and exhalations from the earth, while he explained the pots of Monte Testaccio in Rome as natural impressions in the earth! Olivi of Cremona, in 1584, writes of the fossil conchylia of the famous Calceolarian collection in Verona as mere sports of nature. Michele Mercati prepared good illustrations of fossil bivalves, ammonites, and nummulites in the museum of Pope Sixtus V., and these were published between 1717 and 1719 in the *Metallotheca Vaticana*, by Lancisi, the physician of Pope Clement XI. Mercati names the fossils according to Pliny, and after long discussion comes to the conclusion that they took origin under the influence of the stars.

It is astonishing to find how tenaciously, until the middle of the eighteenth century, so many authors clung to such absurd ideas, even although the fossils were being made known by

means of good illustrations to an ever-increasing number of observers. The works of Aldrovandi, Athanasius Kircher the Jesuit, Sebastian Kirchmaier, Alberti, Balbini, Geyer, Hartley, and many others in the seventeenth century contain some very good figures, and extended the knowledge of the fossils found in various European localities. The fossils were, however, treated usually as mineral curiosities, or as illusions of nature, sometimes as forms called forth in the earth by *vis plastica* or some other force, sometimes compared with living mussels, snails, sea-urchins, plants, etc., and named accordingly.

Probably the greatest representatives of this literature are the Englishmen Lister and Lhuyd (Luidius) and the Swiss Nikolaus Lang. Martin Lister[1] had an excellent knowledge of living conchylia. He had also observed that certain rocks are present over a definite extent of surface, so that maps might be constructed with respect to the distribution of different kinds of rock, and further, that the fossil bivalves and snails differed in the different kinds of rock. He therefore laid down the important principle that the different rocks might be distinguished according to their particular fossil contents, although, strange to say, he thought the rocks themselves had the power to produce the different forms of fossils. Lister warmly combated the idea that the fossils could have proceeded from animals (*Philos. Trans. Roy. Soc. London*, 1671). Nevertheless, he illustrated living and fossil conchylia side by side with one another, in order to demonstrate their resemblance, at the same time writing in the text, that the fossil conchylia were mere rough imitations of the real forms—imitations produced in the rocks by some unknown causes.

The English antiquary, Edward Lhuyd (Luidius), described a thousand species of British fossils in a long and beautifully illustrated work. Lhuyd's theory of "Aura seminalis" strongly recalls the fanciful doctrines of Anaximander and Theophrastus. In a letter, "De fossilium et foliorum mineralium origine," to the famous zoologist John Ray, Lhuyd sets forth how the fossils have developed from moist seed-bearing vapours which have risen from the seas and entered into the strata of the earth.

[1] Lister was born at Radcliff in 1638, studied in Cambridge, and was highly respected in York and London as a medical man. In 1698 he accompanied the English ambassador, Lord Portland, to Paris, in 1709 became house physician to Queen Anne, and died 1711.

Lhuyd found an enthusiastic supporter in the Lucerne physician and councillor, Karl Nikolaus Lang, whose *Historia lapidum figuratorum Helvetiæ* (Venice, 1708) contains 163 plates, with a number of good figures of fossils. Lang is one of the last authors who believed in the direct origin of the fossils in the rocks.

A semi-tragic, semi-comic event brought this literature to a close. Johannes Bartholomew Beringer, a professor in the University of Würzburg, published in 1726 a palæontological work entitled *Lithographia Würceburgensis*. In it a number of true fossils were illustrated, belonging to the Muschelkalk or Middle Trias of North Bavaria, and beside these were more or less remarkable forms, even sun, moon, stars, and Hebraic letters, said to be fossils, and described and illustrated as such by the professor. As a matter of fact, his students, who no longer believed in the Greek myth of self-generation in the rocks, had placed artificially-concocted forms in the earth, and during excursions had inveigled the credulous professor to those particular spots and discovered them! But when at last Beringer's own name was found apparently in fossil form in the rocks, the mystery was revealed to the unfortunate professor. He tried to buy up and destroy his published work; but in 1767 a new edition of the work was published, and the book is preserved as a scientific curiosity. Many of the false fossils (Lügensteine) may be seen in the mineral collections at Bamberg, and there are also specimens in the university collections of Würzburg, Munich, and other places.

Contemporaneously with these mistaken efforts in the sixteenth, seventeenth, and early part of the eighteenth century, a truer appreciation of fossils was gaining ground.

In the year 1580, the famous French worker in enamel, Bernard Palissy, published a book in which he discussed the origin of petrified wood, the occurrence of fossil fishes in Mansfield slate, and fossil molluscs in various rocks. Palissy rightly pointed out that many of the fossil conchylia were identical with living species, and said they must have developed in localities which had previously been under fresh or sea-water. Palissy's ideas were violently attacked by his compatriots, and he was denounced as a heretic in his philosophical and scientific writings, just as he was a Huguenot and a heretic in his religion.

Fabio Colonna [1] upheld similar views in Italy. He tried to show that the "Glossopetren" were not tongues of serpents but the teeth of dog-fish, which occurred along with remains of marine bivalves and snails in certain strata; while in others he recognised the remains of terrestrial animals and plants.

During the seventeenth century Nikolaus Steno and other Continental geologists contested the erroneous and ludicrous ideas of their contemporaries; while in England, Robert Hooke, John Ray, and John Woodward guided scientific thought to the true explanation of fossil remains. Leibnitz, the founder of the Academy of Science in Berlin, and Scheuchzer, the Swiss geologist, further advanced the scientific research of fossils, so that, by the middle of the eighteenth century, no man of science and letters believed that fossils might be products of the earth itself.

The English physicist and mathematician, Robert Hooke (1635-1703), was one of the most brilliant original thinkers of his own or any age. It was he who for the first time suggested the use that might be made of fossils, in revealing the historical past of the earth. In an important work upon earthquakes written in 1688,[2] he stated that fossil molluscs deserved to be regarded as historical, since they represented monuments no less valuable than coins and manuscripts, but he added that it certainly would be extremely difficult to construct a chronology of the earth upon the evidence of fossils. Many fossil Ammonites, Nautilids, and other conchylia undoubtedly differed from known living forms, but he said it had to be remembered how scanty was the existing knowledge of marine animals, especially of those which inhabited the greater ocean depths. Hooke, however, inclined to the opinion that the fossils of unknown forms might really be extinct species, annihilated by earthquakes. He regarded it as certain that a number of fossil species had been confined to definite localities. And from the occurrence of fossil Chelonias and large Ammonites in the strata of Portland Isle, Hooke concluded that the climate of England had once been much warmer. This was explicable, in Hooke's opinion, upon the assumption either that the earth's

[1] *Osservazioni sugli animali aquatici e terrestri*, 1616.

[2] This treatise is published in the *Opera posthuma Robert Hooke*, ed. Rich. Waller, London, 1705.

axis of rotation or the earth's centre of gravity had undergone changes of position.

Hooke further gave some valuable hints about the alteration of organic remains by the process of petrefaction, and cited as examples the petrified stems of trees in Africa and in the kingdom of Ava. His explanation of the elevated position in which fossil marine organisms are now found was based upon his theory of earthquakes. Earthquakes, he thought, transformed plains into mountains, and continents into ocean basins. He attributed earthquakes and volcanic eruptions to the agency of subterranean fire.

Scarcely had the organic origin and historical significance of fossils been successfully vindicated, than the doctrinal influences of the day stepped in and claimed all fossil forms as vestiges from the earlier creation interred in the earth during the great Deluge. The "Diluvialists" formed a powerful party amongst the geologists of the seventeenth and eighteenth centuries, and were warmly supported by the Church. In England, Woodward, Burnet, and Whiston had strong convictions in this direction; while in Germany, Wedel and Baier, and in Switzerland Johann Scheuchzer, taught that all fossils had been spread through Europe during the Flood.

Scheuchzer had in his first work (*Specimen Lithogr. Helveticæ Curiosæ*, 1702) regarded fossils as sports of nature, but under the influence of Woodward's work, which he translated into Latin, he became an enthusiastic believer in the theory of a diluvial distribution of fossils. His natural history of Switzerland contains a special chapter, which professes to deal with the fossil remains left by the Flood in Switzerland. Towards the close of his life, Scheuchzer thought he had discovered in the beds of Oeningen "the bony skeleton of one of these infamous men whose sins brought upon the world the dire misfortune of the deluge." But the supposed *homo diluvii* from Oeningen was afterwards determined by Cuvier to have been a gigantic Salamander, and was called *Andrias Scheuchzeri* in honour of its Swiss discoverer. The original specimen of Scheuchzer's *Andrias* is now in the Teyler Museum at Haarlem.

The strong personality of Scheuchzer and his success as a teacher won for him during his life-time a large circle of scientific supporters, and contributed not a little to a more

general interest in fossils. Numerous books and treatises began to appear, sometimes describing the fossils in particular localities, sometimes of a more dilettante character.

In Switzerland, Johann Gesner's work continued the lines of research initiated by Scheuchzer. Bourguet in Neuchâtel, and afterwards Burtin in Belgium, published handsome plates of fossil illustrations, but the descriptions in the text are not of much value. Johann Baier, the Altdorf Professor, published in 1712 his *Oryctographica Norica*, one of the best works of the time, and in 1757 a supplement of fifteen folio plates was added under the direction of his son Ferdinand.

France, until the middle of the eighteenth century, had a remarkably poor palæontological literature. Antoine de Jussieu in 1718 described the Carboniferous plants of St. Chamont, near St. Etienne, and said they had been brought by the flood from India and the New World to Europe. In a second treatise, Jussieu described fossil Ammonites; he certainly compared these with *Nautilius Pompilius* of the Indian Seas, but he explained them as having been brought from the Oasis of Ammon to France by inundations of the sea. Bertrand's *Dictionary of Fossils* and other minor works testify that France was not devoid of interest in fossils, although activity in this field of research was much more prolific in the neighbouring countries.

In France, during the eighteenth century, only the writings of Guettard can be placed in the same rank with the monographs of particular fossil groups prepared by Rosinus, Wagner, Erhart, Breyn, and Klein.

The outstanding work of this period is undoubtedly that of Knorr and Walch in four volumes, *Die Sammlung von Merkwürdigkeiten der Natur und Alterthümer des Erdbodens.* The first volume was written by the Nürnberg collector and artist, George Wolfgang Knorr (born 1705, died 1761), and the other three volumes were prepared after the death of Knorr by Professor Walch[1] of Jena.

The first volume bears on its title-page an illustration of the famous Solenhofen quarries, and contains figures of fossil crabs, fishes, crinoids, together with dendrites, and "ruin marble"

[1] Johann Ernst Immanuel Walch (1725-78) was a son of J. G. Walch, Professor of Philosophy and Poetry in Jena. In 1759 Walch succeeded his father as Professor, but his chief delight was in Mineralogy and Palæontology, and he made a famous collection.

found in the calcareous slates and flagstones of Solenhofen. The first half of the second volume contains illustrations of molluscs, brachiopods, and echinids, and the descriptive text by Walch embraces practically all that was known in the previous literature about these fossils; in the second half the same treatment is given to so-called "corallioliths" (sponges and corals), to encrinites (crinoids), to osteoliths (fossil bones), to belemnites, dentalites, vermiculites, and balanoids.

The third volume begins with a dissertation about fossil wood, followed by the description of a number of Carboniferous plants. The chapter on the fossil Crustaceans which received the name of "Trilobites" from Walch, ranks far above all previous descriptions of these interesting fossils. The remainder of this volume is devoted to the description of supplementary plates. The fourth volume contains a systematic summary of all fossil forms treated in the foregoing volumes. The masterly text of Walch sets forth his own original observations, and displays a knowledge of the older literature unsurpassed for its completeness and accuracy.

With the exception of Knorr and Walch's important work, palæontographical literature up to the middle of the eighteenth century stands on a low scientific level. This seems the more remarkable when one compares the formal descriptions of fossils, and speculations about their origin and their scriptural significance, with the well-directed efforts of botanists during the same period. Botanists had already brought the systematic arrangement of plants to such a point that only the nomenclature of Linnæus was required to make it serve as a secure basis for the further progress of research. But so far, in the kindred study of the history and classification of animals, no fundamental principles had been attained. It is true some of the more advanced writers, such as Hooke, had said that certain fossil species might possibly be extinct forms. Yet, when from time to time ammonites, trilobites, crinoids, and other fossils were found which had no known existing counterparts, the authorised treatment was to take for granted there might be living representatives existing at depths or in regions of the ocean hitherto unexplored.

Interest centred in the chimeric hope of finding living specimens of these mysterious fossils, and no observer had yet conceived the far bolder, grander dream of defining successive

periods of the earth's history by means of an ordered array of extinct fossil forms.

Hypotheses of the Earth's Origin and History, and Beginnings of Geological Observation.—The keen interest in minerals and fossils and the flourishing condition of the mining industry gradually attracted the attention of scientific men to the investigation of the earth itself. Two methods of research, the empirical and the speculative, developed alongside one another. The one had for its immediate aim the determination of facts, and in its further outlook, the possible construction of some suitable theory; the other contented itself with a minimum of observation, accepted the risks of error, and set about explaining the past and the present from the subjective standpoint. This latter method naturally attained no higher results than the geogenetic fantasies of classical antiquity. And it certainly could never have gathered sufficient energy to roll aside the mass of philosophical and doctrinal tradition that blocked the path of progress.

Throughout the later and Middle Ages, water and fire still continued to be accepted as the two essential active and formative forces dominating the earth's configuration, hence it was unavoidable that the conceptions of the ancient philosophers should re-appear again and again in the newer theories, if in renovated form. Meantime there were in every land of Europe empiricists who were patiently contributing new data to the knowledge of chemistry, of physics, and the constitution of the earth's crust, and were thus preparing the only possible foundation of a science of geology.

Leonardo da Vinci deserves an honoured place amongst the founders of geology, as one of the first who investigated the earth's structure upon scientific principles. Not only did Da Vinci recognise the true origin of fossils, but his artistic sense of form and his close observation of nature revealed to him in the North Italian valleys the agency of running water in sculpturing the earth's surface. He showed how rivers erode their valleys, and deposit pebbles on valley terraces; how a fine detritus accumulates at river mouths, and plants and animals are buried in it; how the organic remains then pass through physical changes and become petrified while the river mud hardens into solid rock, and finally the rock

containing the imbedded fossils rises above sea-level and becomes dry land.

Agricola, the mineralogist, also made a number of useful observations about springs, earthquakes, active and extinct volcanoes, volcanic rocks, the action of running water, and atmospheric movements.

Giordano Bruno, who was burnt at Rome in 1600 for heresy, was a natural philosopher of considerable insight. A reprint of his ideas appeared quite recently (*Boll. Soc. Natur. Napoli*, 1895). Bruno described the earth as a spherical body, on whose surface the depths of the oceans were greater than the height of the mountains; the mountains were no higher in proportion to the size of the earth than the wrinkles on the skin of a dried apple. Bruno also denied that there had ever been a universal Deluge, but brought forward evidences of frequent alteration in the distribution of land and sea. He also directed attention to the position of volcanoes in the immediate proximity of the sea, and from that he argued that thermal and volcanic phenomena might be due to some interaction between surface waters and the interior of the earth. Bruno's ideas were not understood by his contemporaries and were neglected.

No writer was more appreciated in his time than the accomplished Jesuit, Athanasius Kircher.[1] His famous work, *Mundus subterraneus*, begins with the consideration of the centre of gravity of the earth, and the form and constitution of sun, moon, and earth. Book III. is devoted to hydrography, another book (*Pyrologus*) treats of the earth's interior, volcanoes, and winds. Kircher's idea is that there are innumerable subterranean centres of conflagration (*pyrophylacia*), which are connected with active volcanoes; similarly that there are special water cavities in the earth (*hydrophylacia*), which are fed from the sea and are connected by branches

[1] Athanasius Kircher was born 2nd May 1602, at Geisa, near Eisenach, and died 1680, in Rome; was educated in the Jesuit College of Fulda, and took orders in 1618 at Paderborn. He was an accomplished linguist, and travelled through Sicily, Malta, and the Lipari Islands, visiting Etna, Stromboli, and Vesuvius. He was made a Professor in Würzburg in 1630, but on the approach of the Swedes in 1633, took flight to Avignon, and afterwards accepted the post of teacher of Mathematics in the Collegium Romanum in Rome. There he founded a valuable natural history collection, which was afterwards described by Bonanni in 1709 under the name of Museum Kircherianum, and is still kept up in Rome.

in all directions with the earth's surface, at which they appear as thermal springs. Kircher follows Aristotle's view of the origin of springs, lakes, and rivers. Books VI., VII., and VIII. treat of the earth's composition, but offer no description of the different rocks such as one might expect; they describe in diffuse style the salts that occur in the earth, and the constitution and uses of sand, clay, cultivated soil, etc. The consolidation of loose material into rock is ascribed to a petrifying force (*vis lapidifica*) inherent in the earth, while a form-giving force (*Spiritus architectonicus* or *plasticus*) is said to produce all kinds of shapes and figures, for example, crystals, precious stones, stalactites, and fossils.

Book X. is devoted to mines and minerals. Kircher relates that through the medium of Jesuit priests, he put several questions to the miners at Neusohl in Hungary. Some of these referred to the conditions of temperature in the mines—whether the heat increased as greater depths were reached below the surface, and if there were any signs of subterranean fire. The answer from Schemnitz was that in a well-ventilated mine the heat was scarcely perceptible, but that with poor ventilation the mines were always warm. Johann Schapelmann, an official of the mines in Herrngrund, reported as follows:—"In dry mines the temperature steadily increases in proportion to the depth below the surface; where water lies, the heat is less; it is greatest in the parts of the mines where marcasite occurs." This is the first observation of the steady increase of temperature with added depth.

In spite of its many weaknesses and inaccuracies, Kircher's *Mundus subterraneus* must always command a high place in the literature as the first effort to describe the earth from a physical standpoint. It was followed in 1672 by the publication of the *Geographia generalis* of Varenius, a work far exceeding that of Kircher in critical insight and methodical treatment. It is valued as the fundamental work in the domain of geophysics.

Nikolaus Steno[1] was one of the most enlightened geologists of

[1] Nikolaus Steno was born 1638 at Copenhagen, studied medicine and anatomy at Copenhagen and Paris, travelled in Holland, France, and Germany, and settled in Padua. He was called to Florence to be house-physician to the Grand Duke Ferdinand II., and was afterwards the tutor of the sons of Cosmo. Steno then accepted an invitation sent by Christian V. of Denmark, to return to Copenhagen as Professor of Anatomy; but

the seventeenth century. Steno begins his work on the earth's crust by comparing fossil teeth found in the deposits of Tuscany with the teeth of living sharks. He then investigates the origin of fossiliferous deposits and compares them with unfossiliferous rocks. The latter, he says, were formed before life existed on the earth, at a time when the earth was enveloped in a universal ocean. Homogeneous and fine-grained rocks represent, according to Steno, the primitive earth-deposits which segregated universally from the undivided ocean. If, on the other hand, a rock-stratum be composed of particles varying in character and size, or if it comprise large fragments derived from other rocks or fossil remains, such a layer represents a partial deposit of later origin.

Steno argued from the traces of salt and the presence of marine animals, and even ship flotsam in certain deposits, that these had been formed on the sea-floor, whereas the presence of a terrestrial fauna and of rushes, grasses, and the stems of trees in other deposits, indicate that those had accumulated in fresh-water basins. Steno was the first to enunciate definite natural laws governing the formation of a stratigraphical succession in the earth's crust; these may be condensed as follows:—(1) a definite layer of deposit can only form upon a solid basis; (2) the lower stratum must therefore have consolidated before a fresh deposit is precipitated upon it; (3) any one stratum must either cover the whole earth, or be limited laterally by other solid deposits; (4) during the period of accumulation of a deposit there is above it only the water from which it is precipitated, therefore the lower layers in a series of strata must be older than the upper.

But Steno also realised that a series of strata originally horizontal might become relatively displaced by subsequent earth-movements. He cited examples of *local crust-inthrow*,

Steno had become a Roman Catholic, and his stay in his native city was embittered by the enmity caused on account of his religion. He returned to Florence, and was made Apostolic Vicar of Lower Saxony, dying in Schwerin on the 25th November 1687. By command of the Grand Duke Cosmo III. his body was brought to Florence and buried in the Cathedral of St. Lorenzo.

Steno's work, *De solido intra solidum naturaliter contento*, was first published in Florence (1669), and was intended merely as the prodrome of a larger work, but no later work appeared. A second edition was printed at Leyden in 1679, but the original text of Steno's little work is now a bibliographical rarity; its contents are known chiefly through the medium of Elie de Beaumont's French translation published in 1832.

showing how individual strata might remain horizontal, while others might be tilted or even be thrown into a quite perpendicular position, others again might be bent into the form of arches. The occurrence of crust-inthrows, together with the effects of surface denudation, might give shape to mountains and valleys, plateaux, and low-lying plains. Mountains, he said, might also originate from upward action of the volcanic forces in the crust. In cases of active volcanic eruption, ashy and fragmental rock materials were ejected, intermixed with sulphurous vapours and mineral pitch.

Thus Steno's work already contained the kernel of much that has been under constant discussion during the two centuries which have passed since his death; and if one reads the most recent text-books of geology, it will be evident that science has not yet securely ascertained the share that is to be assigned to subsidence, to upheaval, to erosion, and to volcanic action in the history of the earth's surface conformation in different regions.

Descartes (1596-1650), in his *Principia Philosophiæ*, founded a cosmology upon his famous principle of the constancy of the amount of motion or "momentum" in the universe. The earth, he states, like all other bodies of the universe, is composed of primitive particles of matter in which a whirling motion is inherent, and they have aggregated themselves into the form of a sphere. During the gradual cooling of the earth the outer layers consolidated as a firm crust, while the nucleus still continued incandescent. The coarser and heavier primitive particles of the earth, as they rotated, collected round the centre, while the finer and lighter particles gathered in the outer regions and formed the crust, composed of metallic, saline, and aqueous parts. Crust-rupture has from time to time given origin to continents, seas, mountains, and valleys; according to Descartes, volcanic phenomena and fissure injections are results of the high temperature of the earth's interior.

G. F. Leibnitz (1646-1716), the mathematician and physicist, accepts in his *Protogæa* the Cartesian view, that primitive matter had a fluid consistency owing to the tremendous initial heat, and that the earth's spherical form was derived from the aggregation of whirling ultimate elements or "monads" of matter. In place of the Cartesian principle of momentum, Leibnitz starts from a dynamical basis, and assumes a force

which accomplished the separation of light from darkness, or, as he also expressed it, the separation of the more *active* elements of the universe from the more *passive*. A further differentiation of the inactive elements, according to their stability and degree of resistance, determined the dry land and the oceans. The escape of heated material from the interior of the earth produced slaggy spots on the earth's surface, and as these increased a glassy crust was formed. Thus the earth was gradually converted from the condition of a radiant sun to a dark planet. The cosmical theories of Leibnitz suffered in the original from a want of clearness in the diction, and are strained on account of the author's conscientious effort to present a historical account of the earth's surface that should be in harmony with the Mosaic genesis.

That part of the *Protogæa* which deals with mineralogy is much more practical. His official position at the Court of Hanover enabled Leibnitz to become acquainted with the mines and the natural products of the Harz mountains, and he gave an account of the mode of occurrence of the metals and minerals. He also supplied a detailed description, with illustrations, of a number of fossils occurring in Hanover and Brunswick in the copper schists.

If Leibnitz was careful to make his theory of the earth conform with the Mosaic account of Creation, this feeling was far more strongly expressed in England.

Dr. Thomas Burnet, in his *Sacred Theory of the Earth*, published 1681, thinks that in the beginning our earth was a chaotic mixture of earth, water, oil, and air, which gradually consolidated into a spherical form. The various rock-ingredients separated out from the primitive chaos according to their weight, the heaviest material accumulating round the earth's centre; this in its turn was surrounded by water, on whose surface the oily material floated, and the atmosphere enveloped the whole. Gradually, the finer particles that had been held in suspension in the atmosphere settled upon the oil and formed a fatty superficial layer that afforded nourishment for the first plants, animals, and human beings.

The earth was oval, and its axis stood upright, in the same plane as the earth's path, hence there were no alternating seasons, no mountains, no seas, no rivers, no storms. It rained only at the poles, but the water filtered at once into the earth's interior. This state of earthly paradise lasted 1600

years, until the moist and fertile superficial layer was dried by the heat of the sun, and began to rend and crack. The waters below became heated, vapours rose, and bursting through the fertile layer, came into contact with the atmosphere. The intermingling of air and vapour produced fearful storms of thunder and lightning and torrential rains.

The superficial layer broke in many places, and portions of it sank into the earth's abysses. As they fell, some parts were crushed, and tumbled in disorder above one another, so that they formed mountains, valleys, and islands. This was the period of the great Deluge, during which plants and living creatures were almost all destroyed. As the floods retreated the present state of our earth was initiated, but it also will one day pass away in a universal conflagration. Then will succeed a second Chaos from which the Golden Age will spring.

Burnet's circumstantial sketch, which in no way militated against Biblical evidences, excited considerable attention, and won for him worldly preferment. But in a later work in 1692, Burnet treated the Mosaic account of the Fall of Man as an allegory, and for this heresy he was dismissed from his appointments at Court.

John Woodward,[1] the collector and palæontologist, was the most famous English representative of the religious school of geologists. His *Natural History of the Earth and Terrestrial Bodies*, etc. (London, 1695), was translated into Latin by Johann Scheuchzer, and had a wide circulation. In this work, Woodward described his collection of fossils, minerals, metals, and rock specimens. He strongly opposed the opinion that fossils could be mere imitative sports of nature, and said they represented past faunas and floras. But he supposed these remains to have been carried to their present position in the earth by a universal flood, the deluge of the Scriptures.

Before the Flood, the earth's surface conformation had been similar to that which we now know, and the ante-diluvial forms of life on the globe had not differed materially from post-diluvial forms. The earth's interior had been filled with

[1] John Woodward, born 1665, in Derbyshire, studied medicine under a practical physician in Gloucester, was appointed Professor at Gresham College in London in 1692, died 1722. He bequeathed his valuable collection and library to the University of Cambridge. One of the most violent opponents of Woodward's views was Elias Camerarius, Professor at Tübingen.

water, which suddenly burst through the earth's crust, and rose above the highest mountains. The earth's crust was entirely disintegrated by this catastrophe, but living creatures, plants, and metals remained intact. As the Flood subsided the disintegrated material sank, and the stratigraphical succession formed with the heaviest rocks in the lower strata and the lighter deposits in the upper horizons.

Similarly the heavy metals, the minerals, concretions, marbles, and heaviest fossils were imbedded in the lowest strata; in the chalk strata were buried the lighter conchylia and echinoderms; while the upper series of sandy, clayey, and marly strata contained the bones of men, four-footed animals, fishes, the shells of terrestrial and fresh-water conchylia and plants.

The post-diluvial epoch had not been disturbed by any further catastrophe; rain had washed away the superficial material from the mountains, and the rivers and streams had carried the detritus into alluvial plains and sea-basins.

William Whiston,[1] another English writer, indulged in still more remarkable fancies about the early history of our globe. He supposed the earth had originally been a comet, which happened to approach the sun, and was melted into a coherent mass. As it travelled away from the sun, a re-arrangement of the earth's material began; the heavier particles formed a solid nucleus, the lighter particles gathered in the superficial parts; the surface was covered by water except where high mountain chains and islands rose above the ocean-level. The Paradise of the Bible was situated in the southern hemisphere, under the Tropic of Capricorn. In the beginning of creation the earth had no rotatory movement round its axis. That did not begin until after the Sin and Fall of Man in Paradise. After the Fall, in virtue of the rotatory movement, the internal heat of the earth radiated towards the surface and encouraged a rich increase of plant and animal life, but also caused a strong development of the human passions. The punishment came:

[1] William Whiston, born 1666, in 1695 became Chaplain to the Bishop of Norwich, and was in 1701 recommended by Sir Isaac Newton as his successor to the Chair of Mathematics in Cambridge. The heterodoxy of his writings caused Whiston to be deprived of his Professorship in 1701. The wide intelligence and imagination of his writing commanded, however, a large circle of admirers, and his *Theory of the Earth* ran through six editions in a very short time. He died in 1753.

on the 18th November 2349 B.C., a great comet stood above the Equator, its tail came into contact for some hours with the earth, shook out waterspouts, and simultaneously the subterranean waters escaped and inundated the earth's surface. The Flood destroyed plants, animals, and human beings.

The famous zoologist, John Ray, in his *Three Physico-theological Discourses* (London, 1693), took much the same standpoint as Woodward. He accentuated, however, the great importance of running water as an agent of surface erosion, and explained the wide continental flats and deserts as a result of the occasional escape of subterranean waters and the occurrence of gigantic floods.

Johann Jacob Scheuchzer, the Zürich professor, turned his attention to geological, geographical, zoological, and botanical pursuits during his frequent travels, and was an ardent fossil and mineral collector. A few geological sections which he made in the neighbourhood of Lake Lucerne were the first attempts in the literature to reproduce bent strata and other features of mountain structure by means of accurate sectional drawing. But his works afforded as little insight into the mineralogical composition and stratigraphy of the rocks, and the distribution of fossils, as those of his predecessors and contemporaries.

Italy, at the beginning of the eighteenth century, possessed two geologists, Antonio Vallisnieri and Lazzaro Moro, who sought to counteract the tendency of their time towards the theoretical construction of an earth history. Vallisnieri (1661-1730), who held the post of Professor of Medicine at Padua, was an enthusiastic fossil-collector, and entered strong protest against the idea that the Flood was accountable for the annihilation of all pre-existing organisms. His writings point out that marine deposits are widely distributed in Italy at both sides of the Apennines, and are also present in Switzerland, Germany, England, Holland, and other lands, and Vallisnieri therefore argues that those deposits prove incontestably the former presence of the sea over these localities. He favours Strabo's doctrine, and explains how different areas of the earth's surface may have frequently undergone relative changes of level, how portions which are now dry land may formerly have been under sea-water. He further explains the presence of marine fossils in these deposits, on the natural assumption that the inhabitants of the sea as they died fell to the bottom, and were there incorporated in the deposits. Vallisnieri

enumerates the known cases of fluctuations of level, and mentions changes going on at Pozzuoli. He gives also a detailed account of the island of Mea Kaumen that appeared off Santorin in the year 1707.

The learned abbot, Antonio Lazzaro Moro (1687-1740), warmly contested the views of Burnet, Woodward, and Leibnitz. Moro's own theory of the earth was based upon the upheaval of the new volcanic island at Santorin. The emergence of the island was marked by earthquake and volcanic disturbances, which went on intermittently for several months. Moro attaches great importance to the fact that the rocks, as they began to rise from the Ægean Sea, were covered with oysters, and that these were afterwards buried by the ejected volcanic material. He then describes the origin of Monte Nuovo, near Naples; and, following Paragallos for the most part, he gives a complete account of the eruptions of Vesuvius from the year 79 A D., and of the eruptions of Etna. His doctrine was that the fossils found in the mountains had originated where they were found, and that the mountains themselves had been upheaved from the sea by volcanic action. All continents and islands had also been upheaved in this way. The stratified material composing some mountains represented the original volcanic ejections, which in consolidating had assumed a certain stratification of a secondary character, such as is presented at Monte Nuovo, Vesuvius, and Etna.

It is unnecessary to enter into the details of the sequence of events drawn up by Moro in the part of his work devoted to the earth's history. With the exception that he follows Vallisnieri in discarding the Flood, the chain of events is designed in harmony with Scriptural authority; and an official affidavit is given in the preface that the book contains nothing which is inimical to the Catholic faith. Moro was highly esteemed in his time, and was very successful in spreading his teaching. But he contributed little that was new to science. Even his doctrine of convulsive upheavals had been largely anticipated by Strabo; while his own contemporary, Robert Hooke, had worked along similar lines, although his writings were unknown to Moro.

A striking contrast to the work of Moro is presented by the *Telliamed* (anagram of the author) of De Maillet. Whereas Moro attributed all continents, mountains, and islands to volcanic agency, De Maillet regards all the rocks of the earth

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as marine deposits. *Telliamed* was written in 1715 and 171(but did not appear until 1748. On account of its heterodox; De Maillet would not allow its publication until after his deatl The book is written in the form of dialogues between a Indian philosopher, Telliamed, and a French missionary. A the heterodox ideas of the author are placed in the mouth c the oriental, and it is left to the listener to adopt them or t reject them.

The subject-matter is divided into six dialogues. The firs dialogue starts upon the hypothesis that in the beginning th whole earth was covered by water. As the water diminishe in volume, mountains, islands, and continents made thei appearance. The highest or primitive mountain-system emerged from the world-ocean at a time when the seas wer very sparsely inhabited by organisms, hence these rocks ar either unfossiliferous or poorly fossiliferous. By the erosio and fragmentation of these primitive rocks the material fc the further formation of rock was obtained. Sediments wer continually in process of deposition in the seas, and th younger the rocks, the more richly they became filled wit the remains of animals and plants. Telliamed also notes tha many species of fossil mollusca are apparently now extinct.

The second dialogue brings forward a number of evidence in support of Telliamed's hypothesis that the level of the ocea was formerly higher. Telliamed reckons the lowering of th sea-level at a foot in three hundred years, or three and a quarte feet in a thousand years. The third dialogue suggests variou methods by which a more accurate determination of the lowe: ing of the sea-level might be obtained. The fourth is devote to fossils, the origin of which from living organisms Telliame firmly believed in. The fifth and sixth dialogues treat of th cosmology of the earth, but are distinctly weaker than the for going. If we except these concluding chapters, the *Telliame* far outshines other geological writings of the eighteenth centur in its wealth of observed facts, its daring originality, and it charm of style.

A few other notable works of the eighteenth century ma be briefly mentioned. The Englishman Needham, writin in 1769, assumed, like Leibnitz, a central fire in the eartl and traced to it the origin of mountains and volcanoe: He thought the concentric arrangement of the strata upo mountains indicated that these strata, and the fossils containe

in them, represented marine deposits that had been pushed upward by the expansive force working centrifugally through the earth. Needham explained the Mosaic "Days" as primitive periods of protracted length.

Justi, in his *Geschichte des Erdkörpers* (Berlin, 1771), regarded all planets and comets as torn fragments of the sun. The Earth was originally a mixture of soft earth and water, mixed with oily and mercurial substances. The spherical form was developed as a result of rotation round an axis. The water taken from the sun distributed itself over the globe, and the latter became enveloped by a vaporous atmosphere. Life began to inhabit the water, and minerals and the various kinds of rock were formed by new combinations of the original ingredients. The whole work is a compilation of fancies hung on a few slender pegs of fact.

Other German writers, Gleichen-Rosswurm, Professor Johann Gottlob Krüger, and Johann Silberschlag, allowed their imagination to carry them into still more glaring absurdities. But it is worth mentioning that Rosswurm, in sketching the development of life on the globe, begins with the existence of infusoria in the sea. The skeletons of these are said to have formed an "elementary earth" on the sea-basin, from which sprang larger and rougher forms of animals, until at last, after immeasurably long epochs, all aquatic forms of animal life had come into existence.

Beginnings of Geological Observation.—The true spirit of research was still kept alive by men who confined themselves to special subjects of investigation, or described the stratigraphy of particular localities.

Friedrich Mylius published in 1704 and 1718 a valuable work on the rocks of the Thuringian district. John Strachey, in England, gave an admirable description of the various kinds of strata present in the coal districts of Somerset and Northumberland (*Philos. Trans.*, 1714 and 1725). Holloway studied the chalk deposits in Bedfordshire (*Philos. Trans.*, 1723).

In Italy, Spada and the Sicilian observer, Schiavo, drew attention to the fossiliferous deposits of the younger Tertiary periods; the Venetian teacher, Donati, compared the present deposits and fauna of the Adriatic Sea with the deposits and fossils at the base of the Apennines. Baldassari contributed a similar work on the deposits near Siena. The traveller

Targioni Tozetti, of Tuscany, occupied himself with the fossil lenticles (*Nummulites*) of Casciano and Parlascio, which he took for corals, and also with the fossil remains of land mammalia that are distributed in the valley of the Arno, in Val di Chiana, and Ombrosa. Targioni showed conclusively that the mammalia had lived in these valleys, and had not been carried there by any diluvial catastrophe, or brought by the Carthaginians.

To Christopher Packe we are indebted for the first geological map of a part of England in his work, *A New Philosophical-Chorographical Chart of East Kent*, published in 1743. The map embraces a district of 32 English miles in the east of Kent, and the descriptions in the text are illustrated in the map by special signatures and lines.

Lehmann[1] had an ample knowledge of the minerals and fossils that occur in the rocks of Prussia. His work, *Versuch einer Geschichte des Flötzgebirge* (Berlin, 1756), contains a wealth of carefully observed data, and an elaborate statement of his ideas about the origin and composition of the earth's crust. Lehmann accepts a universal deluge, which dissolved or carried away in suspension much of the loose surface material of the primeval mountains. The fine earth and clay thus removed was precipitated as horizontal layers on the sides and at the base of the mountains, and formed the stratified deposits (*Flötzgebirge*). As the waters receded, these deposits, together with the remains of plants and animals that had fallen upon the sea-floor, hardened into solid rock.

Lehmann distinguished the primitive rocks from those of derived origin by their greater height, and by the nature of the veins or dykes (*Ganggesteine*) that occur in them. He did not, however, differentiate between the mode of origin of the so-called vein-rocks and the stratified systems. He thought the vein material had also originated from water, but had been laid down in disorder in the early periods of creation before the universal deluge, so that it was vertically or diagonally deposited, and contained few or no fossils.

[1] Johann Gottlob Lehmann was a teacher of mineralogy and mining in Berlin. His writings extend over chemical, mineralogical, geological, and mining subjects. In 1761 the Czarina Catherine elected him Professor of Chemistry, and Director of the Imperial Museum at St. Petersburg, but he died in 1767 from injuries caused by the explosion of a retort filled with arsenic.

The chief merit of Lehmann is his accurate description of the stratified rocks (*Flötzgebirge*). He distinguished thirty successive bands of rock in the stratified system of Ilfeld and Mansfeld, and set forth the geological structure of that district in an accompanying series of diagrams and sections. Many of the terms in his description of the Thuringian deposits were adopted by him from the miners, and have been retained in geological literature; for example, *Zechstein* or mine-stone, corresponding to the Magnesian Limestone and shales or Upper Dyassic group in England; and *rothes Todtliegendes* (*Rothliegende*) or red underlyer, the unproductive basement beds below the ore-bearing, and the equivalent of the Lower Dyassic.

What Lehmann accomplished for the Permian rocks of Thuringia was accomplished by one of his contemporaries, Dr. Füchsel,[1] for the Triassic series in the same district. In his Latin work, Füchsel defined for the first time the scientific use of the terms *Stratum* (Schicht), *Situs* (Lager), and *Series montana* (Formation). He used the term "formation" to signify a succession of strata, which have been formed immediately after one another under similar conditions, and represent one epoch in the history of the earth; and this is the significance which has continued to be attached to the term in geology.

Füchsel recognised nine formations in Thuringia from the oldest or fundamental rocks to the Muschelkalk :—

9. Muschelkalk, or Upper Limestone series (Middle Trias of later authors);

8. The Sandstone series (now Bunter sandstones or Lower Trias);

7. Granular Limestone and dolomitic marls (now *Zechstein* dolomite);

6. The Metalliferous series (*Zechstein*) and copper slate (*Kupferschiefer*);

5. White rocks, with interbedded sand and clay;

4. Red rocks, with interbedded red marble;

[1] G. Christian Füchsel (1722-73) studied in Jena and Leipzig, took the degree of Doctor at Erfurt, and passed the great portion of his life as a physician in Rudolstadt. The results of his investigations are published in two works; the chief work appeared at Erfurt in 1762: "Historia terræ et maris ex historia Thuringiæ permontium descriptionem erecta" (*Acta Acad. elect. Moguntinæ*). The second work was published independently, and is now very scarce, *Entwurf zur ältesten Erd und Menschen Geschichte*, 1773.

3. Slates, with intercalations of marble;

2. Carboniferous series (with this Füchsel erroneously included the *Rothliegende*, or Lower Dyas);

1. Basal, or "Vein" series, forming the summits of the Harz and Thuringian forest, with erect strata.

Füchsel carefully observed and described the fossils characteristic of the *Muschelkalk*, *Buntsandstein*, the *Zechstein*, and other series.

Füchsel's great work, though it was unfortunately but little known during its author's life-time, became practically the model for the Wernerian School of geologists, and, more than any other individual work, laid the foundation of that rapid development of stratigraphical geology which began in Germany in the next generation. He gave to the geological formation a definite palæontological value, and also represented the surface outcrop of the several formations upon an orographical map by means of corresponding signs, letters, or numbers. Füchsel's geological maps were the first of the kind in Germany, and his text was further illustrated by detailed geological sections.

Professor Arduino,[1] in Padua, was the most brilliant of the early Italian stratigraphers. He was the first who sub-divided the stratified rock-succession into *Primitive*, *Secondary*, and *Tertiary* groups. His geological observations were made on the rocks of the Paduan, Veronese, and Vicentine districts and the neighbouring High Alps, and he gave an excellent exposition of the composition, surface outcrop, and order of superposition of the strata in the groups which he distinguished.

According to Arduino, the Primitive rocks are unfossiliferous, and consist of glassy, micaceous, strongly-folded schistose rocks, through which run innumerable veins of quartz. The *Montes secundarii* contain a great number of marine fossils, and are composed chiefly of limestones, marls, and clays. Arduino enumerates several minor groups within the Secondary series, and dwells at considerable length on the uppermost white and reddish limestones, the so-called *Scaglia* (Cretaceous

[1] Giovanni Arduino (1713-95) was Director of Mines in the Vicentine Province and in Tuscany, afterwards Professor of Mineralogy at Padua; he exerted a strong personal influence upon his colleagues in Italy and upon the many foreign geologists that came to Italy for purposes of study. His writings were very numerous and won him great repute. A list of them is given in the *Bibliographie géologique et paléontologique de l'Italie*, Bologna, 1881.

formations). He remarks the huge blocks of granite and schist which bestrew the exposed surfaces of the *Scaglia* rocks, saying that they have been clearly carried here from Primitive rocks exposed in the neighbouring Tyrol. But it remained for a future age to penetrate the mystery of the transport of these massive blocks by ice. Arduino's *Montes tertiarii* consist of a younger and highly fossiliferous series of limestone, sand, marl, clay, etc., and he observes that the materials of these can in many cases be shown to have been derived from the Secondary series.

The volcanic rocks of Northern Italy were comprised by Arduino in a separate group, and their different origin was clearly pointed out; he included in the volcanic group not only true lavas and tuffs, but also the fossiliferous strata with which the volcanic rocks were interbedded. Arduino accordingly referred the origin of the volcanic group to recurrent eruptions and intermittent inundations of the sea.

The first coloured geological map was published by Gottlieb Gläser at Leipzig in 1775. Wilhelm von Charpentier published three years later the *Mineralogy of Chur-Saxony*, which ranks along with the works of Lehmann and Füchsel as a classic in the early geological literature of Germany. The distribution of the principal rocks and formations is shown by means of colours on a large map, and the occurrence of the less important rocks, of mineral veins and volcanic dykes, is indicated by various signs.

Charpentier grouped granite, gneiss, mica schist, porphyry, and limestone together as a basal formation belonging to one and the same geological epoch. Above this basal formation Charpentier distinguished argillaceous schists and slates, and the greywackes of the Carboniferous series; then the Flötz, or ore-bearing group, which he sub-divided according to Lehmann and Füchsel.

Some years later, by the discovery of Goniatites and fossil plants in the slates and greywackes, Von Trebra, an overseer of mines, was able to confirm Charpentier's conclusion, that the true position of these rocks in the succession was above, and not along with the basal formation.

While the foregoing authors were conducting stratigraphical researches in special localities, others were endeavouring to enlarge our arena of knowledge by means of travel and by observations of a more general character extended over wide

areas. One of the most notable workers was the versatile Guettard,[1] who travelled through France, England, Germany, and Poland, and whose great desire it was to reproduce his scientific observations on maps.

Guettard's mineralogical map of France and England naturally cannot compare with the present Geological Survey maps; but it certainly gives so much accurate information regarding the local occurrence of rocks and minerals, and the position of mines, quarries, fossil localities, mineral springs, hot springs, coal, etc., that it can still be used with advantage. The map is not coloured. The accompanying text refers only in a very meagre and unsatisfactory manner to the stratigraphical succession of the rocks.

It was a pet scheme of Guettard's to publish a mineralogical atlas of the whole of France. This gigantic plan was never completed; Guettard, in collaboration with his colleague, the chemist Lavoisier, published twenty-nine parts, and Monnet, in 1780, added thirty-one farther sheets. Indirectly, this idea of Guettard's was productive of very important results, for the preparation of the maps demanded an energetic search in the open field for the necessary data. The enthusiasm of Guettard inspired others, and there rapidly appeared a large number of scientific papers on the mineralogical features of different French terrains. One very interesting paper gives an enthusiastic account of the neighbourhood of Paris, its rocks, its minerals, and a large number of fossils.

Guettard described the processes of land denudation effected by the solvent and destructive agency of rain and rivers, and by the abrasion of the waves. This is probably the first paper in which a systematic account of denudation is given in its relation to changes in the configuration of the earth's surface. But the most brilliant of Guettard's achievements was his discovery of the volcanic rocks in the Auvergne region.

In 1757 he was journeying to Moulins and Riom, when he observed that black stones were very common on the roads and in buildings. Recognising that these were fragments of volcanic lava, Guettard, accompanied by his friend Malesherbes,

[1] Jean Etienne Guettard (1715-86), son of an apothecary, while still a boy displayed a passion for natural history, especially for botany; studied medicine in Paris, afterwards accompanied the Duke of Orleans on his travels, and was made keeper of his natural history collections. In 1734 he was elected a member of the French Academy.

followed the traces of the lava, and was thus guided to the extinct volcanoes in Auvergne, which had up to that time been unknown in mineralogical science. His famous paper, entitled "Sur quelques montagnes de la France qui ont été Volcans," was presented at the Royal Academy of Sciences in 1752, and published in 1756. His paper on basalt was published in 1770.

Giraud Soulavie, abbot at Nîmes, investigated the extinct volcanoes in Vivarais, Velay, Auvergne, and Provence. His chief book, *Histoire naturelle de la France meridionale* (Nîmes, 1780-84), gave an accurate description of the rocks of the neighbourhood. In it Soulavie strongly advocated the volcanic origin of basalt, and described minutely the physical peculiarities and the divisional planes of basalt rock. He also made an attempt to determine a chronological succession of the volcanic eruptions upon the basis (1) of the position of the basaltic flows above or below rocks of other composition and origin, (2) of the preservation of the scoriaceous and slaggy surfaces, (3) of the variations in the height of the extinct craters. Even although the succession drawn up by Soulavie could not be other than faulty, owing to the elementary state of stratigraphical knowledge at that time, it was a remarkable piece of work, and fully justifies for him a high place amongst the geologists of the end of the eighteenth century. His own contemporaries were inclined to see rather the weaknesses than the excellences in the work of the country abbot. Many of Soulavie's conceptions and observations have, however, proved themselves to be eminently fruitful and valuable.

Rouelle, a lecturer on chemistry, seems to have been an exceptionally acute thinker. In a short introduction to a series of lectures on chemistry, Rouelle touched on the origin of the earth and the composition of its crust. He distinguished "an old and a new earth." To the first he reckoned granite, in the latter he placed all calcareous, argillaceous, and arenaceous rocks, together with the fossils contained in them. The fossils were, he said, distributed in the succession of rocks in a definite order of development, and these extinct forms had differed in the different lands according to environment and climate, just as the existing faunas and floras differ in different localities at the present day. Rouelle further explained the coal seams as accumulations of plants; the rough limestone

of Paris as a mass of fossil molluscs, amongst which the genus Cerithia predominated; and the limestones in Burgundy and in the Morvan as similarly an aggregated mass of ammonites, belemnites, and gryphites. Unfortunately, Rouelle published nothing more than the bare outline of his ideas, and they failed to benefit the general development of geology.

A Swedish mineralogist of wide repute was Johann Ferber, who taught first in St. Petersburg, afterwards in Berlin, and finally settled in Switzerland. He was an indefatigable traveller, and wrote interesting series of letters relating his impressions and observations during journeys in nearly all European countries. His description of the neighbourhood of Naples, and still more his account of the ejected rocks of Vesuvius, are among the finest scientific writings of the eighteenth century.

Ignaz von Born, an Austrian, was a learned mineralogist, and a palæontologist of far keener insight than most of his contemporaries. Like Rouelle, he realised the great part that fossils were destined to play in historical geology, observing that successive assemblages of fossils gave indication of the different geographical and climatic conditions which had obtained in the same area during successive ages. In one of his treatises, Von Born recognised that the "Kammerbühel" near Franzensbad was an extinct volcano, but this opinion was at the time attacked and contradicted by Reuss, the Neptunist.

G. L. Leclerc de Buffon.[1]—It was only natural that misgivings should have been aroused in the minds of many thinkers regarding a science whose literature frequently indulged in unfounded and fantastic hypotheses, and whose votaries seemed often to arrive at worldly distinction without having displayed any deep scientific knowledge or accurate observation of nature.

Buffon gave expression to this widespread feeling among his contemporaries when he made the sarcastic remark that

[1] George Louis Leclerc de Buffon, born at Montbard in Burgundy in 1707, was the son of a wealthy land-proprietor and Member of Parliament, Benjamin Leclerc. In the early part of his scientific career, he devoted himself to physics and mathematics, but was appointed in 1739 to succeed Dufay as Director of the Botanical Garden at Paris. He received the title of Count with the surname De Buffon. He died in Paris in 1788.

geologists must feel like the ancient Roman augurs who could not meet each other without laughing. Nevertheless, he resolved to gather together all the actual observations hitherto recorded in geological science, and to construct a more reasonable history of the earth upon this recognised basis.

His first geological work, *Théorie de la Terre*, which was published in 1749, marked little advance upon current literature, but it was an able argument against the principles of the earth's origin held by Whiston, Burnet, Woodward, and Leibnitz, and boldly denounced the popular idea of a universal Deluge. His great work, *Époques de la Nature*, appeared twenty-nine years later, in 1778.

Buffon there enumerates five "facts" of first importance, and five additional "monuments" or comments. The "facts" are physical in character; they postulate the oblate-spheroidal form of the earth; compare the small amount of heat received from the sun with the large supply possessed by the body of the earth; the effect of the earth's internal heat in altering the rocks of the crust; and the presence of fossils everywhere over the earth, even on the tops of the highest mountains. The "monuments" assert that all limestones consist of the remains of marine organisms, and that in Asia, America, and the North of Europe the remains of large terrestrial animals occur at a small depth below the surface, showing that they apparently dwelt in these regions at no very remote age; whereas the deeper-lying remains of marine creatures in the same region belong to extinct species, or are related only to forms now inhabiting far distant seas.

Starting from these axioms, Buffon portrays in very attractive terms the beginning, the past, and the future of our planet. He derives the material of our earth and the other bodies of the solar system from the impact of a great comet with the sun. The earth's material assumed the form of a spheroid flattened at the Poles, and for 2,936 years continued in a molten state. This was the first epoch in Buffon's scheme, and he determined its length of duration by a series of experiments with balls of melted iron of different sizes. In the same way he determined the duration of the molten state to be 644 years in the case of the moon, 2,127 for Mercury, 1,130 for Mars, 5,140 for Saturn, and 9,433 years for Jupiter. The period required for the earth to cool down to its present temperature was calculated by Buffon to be at least 74,800 years.

To the second epoch (*circa* 35,000 years) Buffon assigns the gradual consolidation of the material at the earth's surface. The occurrence of rents in this primitive crust allowed the influx of molten metallic ores, and was the first cause of surface irregularities. At the commencement of the third epoch (*ca.* 15-20,000 years), the cooling of the earth proceeded so far that the atmospheric vapours were precipitated and gave origin to the primitive universal ocean. Then began the development of life in the warm waters and the accumulation of marine sediments. Gradually the mountains and continents appeared, the tapering of the continents towards the south being due to the rush of oceanic currents from south to north. The fourth period (*ca.* 5000 years) was signalised by a sudden accession of the earth's internal heat, with the result that violent volcanic eruptions burst forth, and were accompanied by gigantic convulsions of the earth's crust.

The fifth period saw calm restored, but the equatorial regions were still so hot as to be uninhabitable. Life flourished over large continental regions at the Poles, and the large terrestrial animals, elephants, mastodons, the rhinoceros, and others, came into existence. As the heat continued to diminish, the faunas and floras gradually migrated southward.

The sixth period saw the decimation of a continuous northern continent into several portions, and many local changes in the extent and position of the seas. Man appeared and began to struggle with lower creation for the means of existence.

The seventh period is the epoch of Man's lordship in the world, and this will continue until the earth cools to a temperature twenty-five times colder than that of the present age, when all Creation on the Earth's surface will be annihilated.

Buffon's merit consists in the bold construction and masterly exposition of a theory which for the first time brought the historical possibilities of geology to the forefront. His calculation of the duration of the successive epochs had, it is true, no empirical basis. Yet it made sufficiently clear to all readers the author's desire to insist upon long periods of time for the slow processes of change in the earth's configuration, and for the appearance of successive forms of plant and animal life. Some of the noteworthy advances made by Buffon were the differentiation which he drew between the primitive rocks formed in the second period, and the sedimentary and volcanic

rocks of the next periods; his clear conception that the oldest inhabitants of the ocean had become extinct and been succeeded by younger forms; his allocation of the early home of the large Mammalia in Polar districts; and his belief, based upon the distribution of land faunas, that the Old and New Worlds had once been united as a wide Northern Continent.

The weaker features of Buffon's work are his views about the origin of mountains and valleys, which are far behind those of Steno, and appear to have been taken for the most part from the *Telliamed.* He also neglected to incorporate the important results attained by Lehmann, Füchsel, Arduino, and other stratigraphers. At the same time, Buffon was undeniably one of the most gifted exponents of that speculative direction which characterised the geological writings of the sixteenth, seventeenth, and eighteenth centuries. This period, however, contributed a large amount of useful material towards our knowledge of the earth, and its many theoretical failures brought men at last to a clearer preception that the materials for an accurate history of the earth must be looked for in the earth itself. But the key had not yet been discovered to the solution of a chronological succession of rock-formations; the study of stratigraphy was still in its infancy, and the merest beginning had been made in the investigation of deformation of the crust and mountain structure.

Volcanoes and Earthquakes.—The phenomena of volcanoes and earthquakes have always attracted a large share of attention from geologists, not only in virtue of their majesty and splendour, but also because of their destructive effects upon human life and property. The philosophers of antiquity for the most part associated volcanoes and earthquakes with a molten earth-nucleus, or with special subterranean centres of eruptivity, and the majority of the authors in the sixteenth, seventeenth, and eighteenth centuries supported one or other of these views.

Martin Lister had a theory that when sand or other material with an admixture of sulphur weathered in the atmosphere, the sulphur became heated and exploded, causing volcanic eruptions. Lemery, in 1700, put Lister's theory to experimental test; he showed how a mixture of sulphur, iron filings, and water imbedded in earth becomes heated, and finally bursts open the earthy covering and emits flame and vapour.

The submarine eruptions at Santorin, in 1707, were fully reported by Vallisnieri and Lazzaro Moro, but Mount Vesuvius was the volcano which proved the chief source of interest throughout the sixteenth, seventeenth, and eighteenth centuries, when it was visited by cultured men of all countries during their travels in Italy.

The Royal Librarian in Naples, Father della Torre, in 1755 compiled a complete record of all the active eruptions and other phenomena observed at Vesuvius from 79 A.D. to the middle of the eighteenth century. Valuable information about Vesuvius, Etna, and the surroundings of Naples is contained in the letters addressed by the English ambassador at Naples, Sir William Hamilton, to the President of the Royal Society in London. And the handsome volume, with fifty-nine coloured plates, by the same author still holds its reputation as one of the most trustworthy historical and scientific accounts of Mount Vesuvius.

The progress of travel in the sixteenth, seventeenth, and eighteenth centuries gradually added a knowledge of the wide distribution of volcanic mountains. Besides the S. European volcanoes and Mt. Hecla in Iceland, geographers recognised the active volcanoes of Kamtschatka, of Japan, the Sunda Isles, the Philippines, the Canary Isles, the Azores, the West Indies, Mexico, and Peru.

Meantime Guettard's discovery of the extinct volcanoes of Auvergne gave a new impulse to the mineralogical study of the volcanic rocks in that vicinity.

Nicolas Desmarest, a French Professor, opposed Guettard's erroneous conception that the Auvergne basalt pillars had crystallised from a watery fluid, and demonstrated the resemblance of the Auvergne basalt to certain recent lavas. He showed that in the Auvergne district true basalt is frequently covered by volcanic ashes or rests upon ashy material, that the transition in the field from basalt to true lava is quite gradual, and that the basalt everywhere presents the character of a volcanic mass that has been originally molten and has afterwards consolidated. He thought, further, that basaltic rock frequently showed transitions to porphyry (trachyte and phonolite), and this again into granite, and concluded that all these rocks probably originated from a molten state, the granite representing rock solidified from a less fluid state of the volcanic magma, and basalt

representing rock formed from a completely molten magma. In spite of Desmarest's mistaken views about the relationship of basalt to porphyry and granite, he was the first clear exponent of the igneous origin of these rocks. He was besides a pioneer in the comparative method of studying the igneous rocks. Papers confirming Desmarest in his estimate of the igneous origin of basalt, porphyry, and granite were contributed by Raspe in Hesse, by Professor Arduino in Padua, and by Mr. Strange, the English consul in Venice.

Faujas de Saint-Fond (1742-1819), Professor in the Museum of Natural History in Paris, brought forward conclusive evidences of the igneous origin of basalt in his famous work entitled, *On the Extinct Volcanoes of Vivarais and Velay.* The work contains a detailed mineralogical investigation of the ejected material of active volcanoes, and compares them with the rocks present in Vivarais and Velay. In the course of his journeys in Southern France he found a volcanic tuff identical with the Pozzuolo earth, and established the flourishing industry of the preparation of cement. Saint-Fond's descriptions and illustrations of the extinct volcanoes in Vivarais and Velay are excellent, and have scarcely been surpassed in later publications.

The fearful earthquake which destroyed Lisbon in 1755 was made the subject of a large number of scientific inquiries into the causes of earthquakes. William Stukeley's theory, attributing earthquakes to electrical disturbances, gained a certain amount of support abroad. Another Englishman, Mr. Michell, suggested that the sudden expansion of vapours enclosed in fissures and cavities of the earth's crust caused earthquakes and volcanoes, the upheaval of mountain-systems, and the deformation of the rocks.

THIRD PERIOD—THE HEROIC AGE OF GEOLOGY, FROM 1790 TO 1820.

The characteristic features of this age, and that which gave it a rejuvenating significance in the development of geology, was the determined spirit that prevailed to discountenance speculation, and to seek untiringly in the field and in the laboratories after new observations, new truths.

Interest was directed, in the first place, towards the investigation and description of the accessible parts of the earth's crust. The composition and arrangement of the strata were studied with enthusiasm. The bolder inquirers ventured into wild recesses of mountain-chains and climbed snowy peaks, whose difficulties had hitherto been thought insurmountable; travellers explored the uninhabited plains of Siberia, the remote mountain-ranges of Asia and America, and brought home with them new scientific material and observations of the highest importance for comparative research.

The illustrious Professor of Mineralogy at Freiberg, Abraham Gottlob Werner, exercised an unrivalled authority amongst the followers of the strict descriptive method in natural history. By the skill and eloquence of his teaching, far more than by his books and writings, Werner inspired in his scholars and adherents a devotion towards exact methods of study. The public lectures given by Werner systematised for the first time the subject-matter that should properly come within the domain of that rapidly growing branch of science for which he originally suggested the name "Science of Mountains," but afterwards called "Geognosy." Werner included in his system of geognosy the mineralogical identification of the rocks, also the minerals present in them, and their special places of occurrence, the determination of the stratigraphical position of the rocks, their thickness, and mutual relationships, as well as the conditions under which they took origin.

Under the term "geology," suggested by De Luc, Werner would only recognise theoretical speculations about the origin and history of the earth. Great though the advantages of Werner's method were, it was not without its weaknesses. The chronological succession of the individual members of a formation was not determined with sufficient precision, the fossils were scarcely used in determining the age of a rock stratum, and the history of organic creation was not even recognised as a subject of investigation in geognosy.

In this respect the great pioneer was the English engineer, William Smith. He was the first to make known on incontestable evidence that the stratified rocks of England could be most securely identified and arranged in chronological order according to their organic contents. Smith's method of determining the age of rock-strata from the organic remains found

in them provided an inestimable complement to Werner's system, since the latter rested in the main upon mineralogical distinctions. William Smith has received the merited appellation of "father of historical geology." Two French scientists, Alexandre Brongniart and Cuvier, attained similar results, independently of William Smith, from their examination of the fossils in the rocks of the Paris basin.

Thus the knowledge and comparative investigation of fossil faunas and floras came to be recognised as a leading feature in the study of rock-formations. Rapid studies were made in the new direction of research by Cuvier, Brongniart, Lamarck, Schlotheim, Sowerby, and others. The name of Palæontology was given to the special department of zoological and geological science that treated of extinct organic forms.

During this period (1780-1820), while advances were being made in empirical methods of study, the theoretical aspect of geology remained for the most part on the old lines.

The theories of the universe presented by De Luc and De la Métherie are largely imaginative. Cuvier's Catastrophal Theory still betrays the dominating influences of the older literature. Werner's hypotheses about the origin and development of the earth scarcely rise above the ideas current in the seventeenth and eighteenth centuries. Indeed, the erroneous views held by Werner with regard to the origin of basalt and of volcanoes, together with the one-sided character of his Neptunistic doctrines, appreciably retarded the progress of geology.

The opponents of the Neptunistic doctrines were the Plutonists and Volcanists, who numbered in their ranks many observers of world-wide repute—*e.g.*, Hutton, Dolomieu, Von Humboldt, Von Buch, Breislak. Yet the early Plutonists had no great array of facts before them, and their teaching was necessarily inadequate for purposes of generalisation.

On the whole, however, the close of the eighteenth and beginning of the nineteenth century was a period made memorable in geology by the pioneer labours of a brilliant phalanx of scientific men—Werner, Saussure, Humboldt, Hutton, W. Smith, Cuvier, Brongniart, and others. Their works and teaching stirred new activity and interest in this branch of research in the mining-schools of Europe, and numerous adherents gathered round the intellectual heroes of the age. Students were attracted by the freshness of the

mineralogical and geognostic discipline, as it now came to be enunciated in professorial courses of lectures, and above all by enthusiasm for a science which had largely to be pursued out-of-doors, and therefore offered wide scope for the physical as well as the mental energies of youth.

Following the guidance of their great leaders, a numerous band of workers, by their unabated zeal in collecting and identifying fossils and rock-specimens, no less than by unremitted observations in the field, established the young science of geology upon a platform of equality with other spheres of scientific knowledge.[1]

Pallas and De Saussure.—Pallas and De Saussure are two of the few scientific men of the latter half of the eighteenth century who endeavoured to explain the surface conformation of the earth upon principles of stratigraphy and structure. Peter Simon Pallas, born in Berlin in 1741, came of a highly

[1] The chief seats of mineralogical and geognostic teaching at this time were the mining-schools; that of Freiberg was founded in 1765, Schemnitz, 1770, St. Petersburg, 1783, and Paris, 1790. Geology was also associated, at least in Germany, with the literature of mining and mineralogy. Voigt published a magazine on mineralogy and mining interests (Weimar, 1789-91). A number of important papers on geology, mineralogy, and mining are contained in C. E. von Moll's *Jahrbücher der Bergund Hüllenkunde* (Salzburg, 1797-1801), a series which continued to be published until 1862. K. C. Leonhard's *Pocket-book* (*Taschenbuch*) *for Mineralogy* was founded in 1807, and soon took the first rank among the German journals, which it has continued to retain to the present day, its title having been changed in 1830 to *Jahrbuch für Mineralogie, Geologie, und Petrefaktenkunde* (Palæontology). Ballenstedt's *Archiv für die neuesten Entdeckungen in der Urwelt* (Quedlinburg and Leipzig, 1809-24, 6 vols.) were chiefly devoted to the occurrence of human remains, diluvial animals, and other fossils, likewise to questions of a theoretical nature. In France, the *Journal des Mines* (Paris, 1795-1815) corresponds to these German publications. From the year 1816, this magazine received the title *Annales des Mines*, which it still bears. The *Journal de Physique*, published by Rozier and De la Métherie, contains a number of theoretical papers by De Luc and De la Métherie, and also important petrographical communications by Dolomieu, Cordier, and others. In England, the Geological Society of London was founded in 1807, and geological and palæontological papers were afterwards published in the *Transactions*, later in the *Proceedings* and Quarterly Journal of this Society; previously contributions in these branches of science had been published chiefly in the *Transactions* of the Royal Societies of London and Edinburgh. In the other European States, scientific Societies and Academies were zealous in the publication of special papers on geological and palæontological subjects.

gifted family. His father was professor of surgery, his mother belonged to the French colony in Berlin. His inborn talent for languages developed early; while still at school, he mastered French, English, and Latin in addition to his native tongue. He studied medicine and natural science at Berlin, Halle, Göttingen, and Leyden, and after a visit to England, settled at the Hague in 1763, to devote himself exclusively to science. The turning-point in his career was an invitation to fill the chair of Natural History in the Imperial Academy of St. Petersburg, and the further request that he should undertake the leadership of an expedition to Siberia, planned by Empress Catherine II.

Pallas spent six years of great privation (1768-74) in Eastern Russia and Siberia, exploring the plains, rivers, and lakes, with a view both to their geography and to their faunas and floras, and he also examined geographically the Ural and Altaï mountains.

Partly during the expedition and partly afterwards, Pallas published a three-volume work containing an account of his travels and observations. Few explorers have contributed such a vast wealth of geographical, geological, botanical, zoological, and ethnographical observations as Pallas has done in this justly famous work.

In 1793 Pallas commenced a journey of two years' duration in Southern Russia and the Crimea. He liked the province of Taurida so well that he afterwards took up residence there upon an estate presented to him by Empress Catherine. He continued his scientific researches for several years, until, failing in health and saddened by the loss of his wife, he returned to his native city in 1810, and died in Berlin in 1811.

Pallas occupied a high position in the scientific world. He achieved his successes mainly in zoological and geographical research, but he also contributed much to the progress of geology. His geological views are contained in a treatise published by the St. Petersburg Academy, *Consideration of the Structure of Mountain-Chains* (1777), and in the *Physical and Topographical Sketches of Taurida* (1794).

John Michell had in 1760 published in the *Philosophical Transactions* a series of observations on earthquakes and mountain-structure. This paper was accompanied by an ideal section through a mountain-system, showing a central core

composed of the crystalline massive rocks, on either side a succession of uptilted and upheaved strata covered in their turn by younger, slightly tilted, or horizontal deposits composing the neighbouring plains. Michell, however, did not draw any general conclusions. Pallas was enabled from his wide experience to fill in the details of Michell's skeleton plan of a mountain-system.

According to Pallas, granite forms the core of all great mountain-systems. It is covered by unfossiliferous schistose rocks of various kinds, serpentine, porphyry, etc. These rest against the granite in highly-tilted or vertical positions, and are themselves succeeded by argillaceous schists and shales, and by thick masses of limestone containing marine fossils. The shales and limestones have highly-tilted positions where they occur in the inner parts of a mountain-system, but become less tilted and horizontal in the outer portions, the number and variety of the fossils at the same time increasing. The low hills and plains are composed either of sandstone, marls, and red clay with stems of trees and twigs of land plants, or of loose material, with the bones of large land mammals. Pallas examined the mammalian remains with great care. He proved the astonishing frequency in the occurrence of mammoth, rhinoceros, and bison in the Siberian plains, and described a rhinoceros corpse with hide and hair complete, imbedded in the sand and pebbles on the bank of the Willui river. He also stated that great accumulations of sand and sulphur occur in the schistose zone of rocks, and that the decomposition of those materials gives origin to volcanic disturbances, which however affect only the rocks above the schistose zone and the granite.

The primeval ocean of the globe, in his opinion, never stood more than 100 fathoms above the present sea-level, so that the granite core of the mountain-chains could not have been covered by it. All mountain-ranges composed of schists, limestone, and younger formations, or, as Pallas called them, the mountains of the second and third order, owed their upheaval to volcanic force. The schist mountains had originated before the creation of living creatures; then the limestone ranges rose above the primeval ocean, and some of these, such as the Alps, in relatively recent periods. The mountains of the third order were due to the last volcanic eruptions. The upheaval of mountain-chains was always accompanied by violent ground-

tremors and by other disturbances of the earth's surface. Great cavities formed in the earth's crust and filled with sea-water; or, sometimes, portions of the continents were devastated by floods. In illustration of this, Pallas said that at the outbreak of volcanic action in the Indian Ocean and South Seas, "*which two seas seem to occupy a position above one common volcanic arc*," the waters of the Equator were forced towards the Poles, and carried northward from India the plants and animals that now lie buried in the loose gravels of the Siberian plains. This was the explanation he gave of the occurrence in such remarkable number of bones of mammoths, rhinoceroses, and buffaloes in Siberia.

Although this explanation and many of his opinions about volcanoes were erroneous, there can be no doubt that Pallas was an accurate observer, and that his broadly conceived delineation of the surface conformation, general sculpture, and physical characters of a huge and hitherto untravelled territory, conferred an inestimable boon on the struggling natural sciences. The works of Pallas have been the basis of all later geological investigations in eastern and southern Russia, in the Ural and Altaï mountains, and in Siberia.

A life-long student of the French-Swiss Alps, Horace Benedicte de Saussure must always be given the place of honour amongst the early founders of the science of the mountains. Born in Geneva in 1740, the scion of a noble and rich patrician family which had already won high scientific repute in the previous century, De Saussure enjoyed in his early years and education every advantage of wealth, culture, and influence. As a boy he rambled in the country around Geneva, diligently collecting plants and minerals. But the mountains near Geneva failed to satisfy the enterprise of the youthful student. At the age of twenty he made his first walking tour to Chamonix, and from that time resolved to devote his life to the study of the Western Alps. Two years later he was appointed Professor of Philosophy at the Academy of Geneva.

In 1787, at the head of a well-equipped party, he carried out the first ascent of Mont Blanc. In the following year he spent eighteen days in the Col du Géant, at a height of over 10,000 feet; and between 1789 and 1792, he climbed the summits of Monte Rosa, the Breithorn and Rothhorn. In

1794 a stroke of paralysis put an end to his mountaineering activity, and in 1799 he died.

Saussure's glowing descriptions of the Alpine world removed the prejudice against the "Montagnes Maudits," and awakened a feeling of enthusiasm for the infinite wonderland of beauty and delight in the higher altitudes of the Alps. Apart from his achievements in science, De Saussure may be regarded as the pioneer of a practically new cult in human enjoyment, the love of mountain-climbing.

His great work, *Voyage dans les Alpes*, is a model of clear language, exact observation, absence of bias, and cautious reserve in forming general conclusions. His style is simple, concise, without rhetorical efforts, yet by no means devoid of elegance. At the outset De Saussure laid down the principle that we need not expect to advance our knowledge of the earth's past by a study of flat plains; that only by solving the problems presented to our view in mountain-systems can we hope to gain insight into the series of biological and geological events in the history of our world. His chief concern was to observe accurately; he placed little importance on theoretical speculations.

The descriptions of his journeys start with the environment of Geneva,—with Mont Salève, the Rhone Valley, and the south-west Jura,—continue into the Dauphiné, across the Tarentaise and Maurienne group, the Mont Cenis Massive, the Ligurian Alps, and embrace the Provence and the Rhone Valley. The district examined in greatest scientific detail was that of Mont Blanc and the Valais group; but he also travelled through the St. Bernard group, the Berne and Gotthard Alps, and the neighbourhood of Lake Lucerne. Everywhere he observed and noted the local varieties of rock and the occurrences of minerals and fossils. He also entered the strike and dip of the strata upon topographical maps, although he made no attempt at geological maps and sections.

In his views on mountains tructure, De Saussure followed Pallas. He showed that in the Western Alps, as in the Ural mountains, a central core of granite, gneiss, and other primitive rocks, was succeeded by stratified but unfossiliferous shales and schists of different kinds. The schistose rocks were most steeply tilted in the Central Alps, where they came into proximity with the primitive rocks, while towards the outer Alps the secondary rocks (limestone, sandstone, conglomerates)

followed in less tilted positions. More striking than this scheme of Alpine structure is De Saussure's admirable description of the fan-shaped arrangement of the schists in the Central Alps of western Switzerland, and his proof that the longitudinal valleys and the chains of secondary rock follow the strike of the strata and the continuation of the main ridge, remaining parallel with the leading or central chain. Saussure further set forth the asymmetry of form presented by the Western Alps, in respect of their gradual descent to the Swiss plains on the north side of the Alps, and their abrupt descent on the Italian side. He examined the mineral composition of the rocks, and the alternation, succession, and position of the different kinds of rock. He also studied the topographical, meteorological, and physical relations in the mountains. A permanent addition to the facts of physical geography was made by his height measurements, his observations of electrical atmospheric disturbances, his determinations of the snow-line, rise of temperature in the ground and in the depths of the lakes, his investigations of glaciers, and of the distribution of plants at different altitudes.

It was not until after the publication of the first two volumes of his work that De Saussure became acquainted with Werner's geognostic and mineralogical writings. He welcomed the new methods and additional knowledge supplied by Werner, and promptly tried to apply them in the district he was himself examining. Hence we cannot blame De Saussure when we find in the third and fourth volumes of his work, certain ideas about rock structure and mountain upheaval that appear contradictory to views expressed in the earlier volumes.

De Saussure also changed his opinions more than once about valley-erosion and about the origin of the immense thicknesses of *débris* and pebble deposits in the Rhone Valley and at the foot of the Alps. Like Professor Arduino of Padua, De Saussure was intensely interested in the nagelflue conglomerates and morainic accumulations and erratic blocks on the outer Alpine slopes, but was no more successful than Arduino in arriving at an explanation. He referred them all to one geological period, during which he thought gigantic inthrows of the crust had taken place, and the waters of the ocean rushing into the crust-basins had fragmented, torn away, and scattered large masses of rock.

With our present intimate knowledge of glaciation, it seems

strange that De Saussure should have provided us with a minute description of the rounded, hummocky terrains in the Alps, which he termed "roches moutonnées," and should even have observed the scratches upon these rocks, and yet have failed to associate such phenomena at lower Alpine levels with anything that he had observed in the higher altitudes. On the other hand, realising as we do to-day the extreme complexity of Alpine stratigraphy, it is readily comprehensible why in spite of the extraordinary number of his observations, De Saussure could not construct from them any definite chronological succession of the rock-strata in the Alps. He certainly differentiated the secondary Alpine rocks from the primitive crystalline masses in the central chain, and distinguished the deposits in the plain of Piedmont as Tertiary.

In his conceptions of the origin of granite, schists, and igneous dykes De Saussure followed Neptunistic doctrines. Finally, after much hesitation, he allowed that the sedimentary series had been deposited horizontally and only subsequently elevated and tilted, but he would not agree to the Volcanistic teaching that volcanic force had upheaved the rocks. Looking back on De Saussure's geological writings, it might seem that from their lack of broad generalisations they had failed to exert a direct influence upon the progress of Alpine geology. Yet their faithful observations have made them reliable books of reference for all Swiss geologists to the present day. De Saussure's love of truth and his passion for nature, combined with the extreme modesty of his attitude towards the science of the mountains, have made him an ideal personality in the annals of Alpine geology.

Endless in his energy, insatiable in his desire to accomplish, De Saussure, at the conclusion of his life's labours, writes that he has found nothing constant in the Alps except their infinite variety. With a feeling of sadness he admits the futility of all his efforts to wrest the eternal truths of nature from the majestic peaks of his native land. Then it was that he wrote his charming book of *Instructions to Young Geologists.* He impresses upon them above all to keep their minds free from bias in favour of one scientific opinion or another, to make it their chief aim to *observe* with the greatest deliberation and detail, to omit nothing as unimportant, and at the same time not to lose sight of the possible value of all facts in establishing the fundamental principles of the science.

A. G. Werner and his School, Leopold von Buch, Alexander von Humboldt.—Abraham Gottlob Werner,[1] Professor in the School of Mines at Freiberg, was the most renowned geologist and mineralogist of his day. A born teacher, Werner combined quickness of observation and a marvellous memory with the capacity to marshal all the facts that came under his notice into natural systematic order, and to reproduce them orally in lucid language at once striking and convincing to his hearers. His first original work, *On the External Characters of Fossils*, placed him at once in the front rank of living mineralogists. His fame rose still higher when he began in 1780 to deliver a course of lectures on the science of rock-formations, or, as he called it, "Geognosy." He derived the fundamental conceptions in his teaching of the formations from the admirable systematic arrangement introduced by the Swedish mineralogist, Tobern Bergman. Werner's creation of the study of rock-formations into an independent academical discipline was far-reaching in its effects. Thoughts that had been vaguely shaping themselves in the minds of a few scientific thinkers, important contributions to knowledge which had been locked up, except for the very learned, in the Transactions of scientific societies, were assimilated and mastered by Werner, and taught by him with such precision and enlightenment that Freiberg became in a few years the European lodestar for the study of mineralogy and geognosy.

The Professor never relaxed his reading and research; his lectures were not written, and they were fresh every year. Kept in touch as he was with all the great academies and universities by the floating body of students whom his teaching attracted,

[1] Abraham Gottlob Werner was born on the 25th September 1749 (according to Frisch, 1750), at Wehrau in Saxony. He belonged to a family which had been actively engaged in the mining industry for three hundred years. His father, who was overseer of a foundry for hammered iron work, taught him in his boyhood to recognise nearly all the known minerals, and after a short period of residence at a school in Silesia, Werner returned to take part in the same foundry as his father. At the age of eighteen he visited Freiberg in the course of a holiday tour, and the sight of the collections and mining schools there roused in him an enthusiastic desire to take up the study of minerals and mining as a career. He studied at Freiberg and Leipzig, and in 1774 published his first paper on "The External Characteristic Features of Fossils." In 1775 Werner was appointed Inspector of Collections and teacher in the School of Mines at Freiberg. This post he held for more than forty years, and died unmarried in 1817.

Werner knew the best of the new work that was being done elsewhere. From all parts of Europe students came, and, when they returned to their own countries, they spread the teaching of geognosy and mineralogy as Werner had taught it to them. It was the spoken word of Werner that carried. Of written words no man of genius could have been more chary. His dislike of writing increased as he grew older, till he could scarcely bring himself to reply to the most important letters. Cuvier relates that the letter which announced to Werner that he had been elected a Foreign Member of the French Academy was left unopened by the Professor and was never answered.

With the exception of a number of mineralogical papers, and a short classification and description of the different rock-formations, Werner published only a single work on the origin of dykes, and a series of very short articles on basalt, trap-rock, and the origin of volcanoes. He never published his academical courses of lectures; for an account of these we have to turn to notes published by his students, sometimes in abridged and sometimes in extended form. Werner had, however, more than once to disown these published notes, as they failed to represent the true sense of his lectures.

The most trustworthy reports of Werner's "geognosy" are probably those written by Franz Ambros Reuss in the third part of his text-book (Leipzig, 1801-3); by D'Aubisson de Voisins in his *Traité de Géognosie* (Strasburg and Paris, 1819); and by Jameson in the *Elements of Geognosy* (Edinburgh, 1808). Werner himself published only one lecture—"Introductory to Geognosy"—delivered at Dresden.

Werner defined "Geognosy" as the "Science which inquires into the constitution of the terrestrial body, the disposition of fossils (*i.e.* minerals, cf. p. 15) in the different rock layers, and the correlation of the minerals one to another." In his lectures, he began with a short epitome of mathematical and physical geography, and with a discussion of the natural agencies which alter the conformation of the globe.

Proceeding to the consideration of the earth's crust, Werner described all the varieties of rock and entered in detail into their structure, their position, their chronological succession, and their technical value as rich or poor metalliferous layers. Certain varieties of rock (shale, limestone, trap-rock, porphyry, coal, talc, and gypsum) were thought by Werner to have been

recurrent groups in the rock-succession, and he treated them as "suites" or series, characteristic of each successive epoch in the earth's history. Largely following the precedent of Bergman, who had distinguished four principal rock-formations, Werner erected five so-called formation-suites in his chronological scheme of the rocks:—

5. *Volcanic rocks*, sub-divided into true volcanic (lava, volcanic scoriæ and ashes, pepperino, tuff) and pseudo-volcanic rocks (burnt clay, jasper, polishing-stone, slag).
4. *The transported or derivative rocks* with the formations nagelflue, sand, clay, pebbles, calcareous tufa, bituminous wood, soapstone, aluminous earth, etc.
3. *The Flötz rocks* with the formations old sandstone, coal, old Flötz limestone, the ore-bearing or "Zechstein" rocks, bituminous lignite, Muschelkalk, freestone and chalk, basalt, pitch-coal, brown-coal, etc.
2. *The transitional rocks* with the formations clay-slate, crystalline schist, greywacke, transitional greenstone, gypsum and the first organic remains.
1. *The primitive rocks* with the formations granite, gneiss, mica schist, slate, primitive greenstone and limestone, quartzite, hornblende schist, porphyry, serpentine, chlorite and talc schist, primitive gypsum, etc. No organic fossil remains.

According to Werner, the primitive rocks originated during the first chaotic period of the earth before the existence of organic creatures, by chemical crystallisation of rock-material from an aqueous solution. In the *transitional* period, the slates and shales were held to represent chemical precipitates; the greywackes to have been mechanical deposits. During the accumulation of the *Flötz* series, periods of disturbance alternated with periods of quiet deposition; the waters frequently receded from land areas, and again inundated the young continents. These varying conditions continued during the succeeding epoch of active transportation, and finally gave place to an epoch of violent volcanic outbreaks, the immediate cause of which Werner believed to be the ignition of deposits of coal in the earth's crust.

Werner's practical knowledge of mining methods served him in good stead when he came to study the strike and dip and relative position of the rocks from a scientific point of view. His application of more exact methods in taking field observa-

tions, and his introduction of a number of new and precise terms for stratigraphical purposes, marked an advance in the study of the earth's crust scarcely less important than his masterly classification of the rocks according to their mineral constitution.

Unfortunately, Werner's field observations were limited to a small district, the Erz mountains and the neighbouring parts of Saxony and Bohemia. And his chronological scheme of formations was founded upon the mode of occurrence of the rocks within these narrow confines. To him in that rich mining district the minerals seemed all-important, and the occurrence of organic remains fell into insignificance. Again, he held strong convictions that the ores present in veins and layers had separated out from supersaturated aqueous solutions of the metals, and he sought to explain in a similar way the origin of the massive granitic and schistose kinds of rock. The Wernerian doctrine was all the more attractive as it seemed so simple. It taught that all the rocks of the crust, like the earth's body itself, had taken origin from aqueous solutions, either as chemical or as mechanical precipitates, while volcanic lavas and scoriæ represented rock-material that had been so precipitated but had subsequently been melted and ejected.

Werner was equally narrow in his ideas about the stratigraphical relationships of the rocks. As a fundamental principle he held that all varieties of rock had been deposited in the same horizontal or tilted positions as they now occupy. But strata inclined at an angle of more than 30° owed their high inclination to local disturbances, such as the collapse of crust-cavities, landslips, etc. These local inthrows and slips exerted little influence upon the connection of the strata as a whole; rather, the successive deposits enveloped the earth with the uniformity of the integuments of an onion.

Werner gave little credence to the opinions of Pallas and Saussure regarding the elevation of wide continental territories and the upheaval of mountain-chains. Like De Maillet and Buffon, he ascribed the inequalities of surface conformation exclusively to the erosive agency of water, more especially to the strong currents created during the retreat of sea-water after its periodic inundations of the land.

Similarly, with regard to the origin of basalt, he came into conflict with the results obtained by the leading authorities on

volcanic rocks in his time—Desmarest, Raspe, Arduino, and Faujas de Saint-Fond. Werner had at first included basalt among the rocks of highest antiquity; subsequently he removed it to the Flötz formation. In 1788, after a visit to the Scheibenberg, a basaltic summit in the Erz mountains, he wrote a special paper on basalt, from which the following passage is extracted:—

"The basalt rock is separated by several beds of sandstone, clay, and greywacke from the basal gneiss. The transition from one stratified bed to the next in upward succession is quite gradual. Even the greywacke merges gradually into the clays below it and the basalt above. Therefore the basaltic, clayey, and sandy rocks all belong to one formation, have all taken origin as moist deposits, precipitated during one particular epoch of submergence in this district.

"All basalt was formed as an aqueous deposit in a comparatively recent formation. All basalt originally belonged to one widely extended and very thick layer, which has since been for the most part disturbed, only fragments of the original layer being left."

Voigt, who had been a scholar of Werner, opposed this so-called "new discovery," and said that the Scheibenberg basalt was of volcanic and not aqueous origin, that it represented an old lava which had flowed over a sandy substratum. A lengthy controversy ensued, in the course of which Werner wrote his paper tracing volcanic activity to the burning of coal in the earth's crust. He argued that during volcanic action basaltic deposits might be converted into lava, if it so happened that the coal-beds were subjacent to the basaltic beds in the crust. The controversy between Neptunists and Volcanists waged for many years in Germany, and much labour and time were lost in the discussion of difficulties which had already been solved in other European countries.

The *New Theory of the Origin of Mineral Veins* was Werner's last contribution to science. His theory was that surface-water descends through crust-fissures; vein-stuff is precipitated from the water, and gradually fills up the fissures. Although this theory is no longer accepted for the majority of ore-deposits, Werner's work proved of the highest value in mineralogical science, since it contained a large store of accurate information about mineral veins, and suggested new methods of determining the relative age of vein-deposits.

So strong was the personal influence of Werner, that the Neptunian doctrines which he inculcated continued to hold their place for several decades—until, in fact, three of the greatest of his scholars, D'Aubisson de Voisins, Leopold von Buch, and Alexander von Humboldt, stepped into the ranks of the opponents of Neptunism.

Leopold von Buch was the most illustrious of the geologists taught by Werner. The later writings of Leopold von Buch, published between 1820 and 1860, are those on which his fame chiefly rests; but from the year 1796 he was actively engaged in travel and research, and his earlier writings contributed in a great degree to establish the science of geology.

Leopold von Buch was born on the 26th April 1774, at the Castle of Stolpe in Pomerania, the son of a nobleman with considerable property. While still a boy he displayed a passionate love of scientific inquiry, and his fondness for chemical and physical mineralogical studies led him to select the Mining Academy of Freiberg for his collegiate course. While there, Alexander von Humboldt and Freiesleben were among his fellow-students, and with them he formed close ties of friendship. He made his home for nearly three years (1790-93) with Professor Werner, for whom he entertained the deepest sentiments of reverence and friendship; and these were in no way altered when, in after years, some of his opinions began to diverge from the teaching of Werner.

Von Buch made several excursions during his student days into the Erz mountains and Bohemia, and published a paper on the neighbourhood of Karlsbad. From 1793 to 1796 he studied in Halle and Göttingen, and became acquainted with Harz, Thuringia, and the Fichtel mountains. In 1796 he accepted office in the Mining Department of Silesia, but resigned in 1797, in order to devote his entire time and energy to travel and research. His stay in Silesia resulted in the publication of an important treatise on the mineralogy of the neighbourhood of Landeck, and an attempt at a geognostic description of Silesia. He spent the winter of 1797 in Salzburg, together with his friend Alexander von Humboldt, and in the following spring set out on his first journey through the Alps to Italy. He visited the Euganean Isles and the district of Vicenza, and stayed for some time at Rome, making frequent excursions into the Albanian mountains. He then spent five months at Naples, and devoted a large part of his time

to Vesuvius. Although during these travels he began to entertain serious doubts about the correctness of Werner's theory of the origin of basalt, he could not convince himself that it was untenable.

After a visit to Paris, Von Buch returned to Berlin in 1799, and was there commissioned to investigate the occurrence of mineral contents in Canton Neuchâtel, which at that time was under Prussian government. Neuchâtel, from which ready access was afforded into the Jura mountains and into the Alps, now became his headquarters. Every observation was carefully entered in his maps, and a number of scientific papers flowed from his ready and graceful pen.

A visit to Auvergne in 1802, and a study of the basalt and trachyte in that area, still further shattered Von Buch's faith in Neptunian doctrines. In 1805 he was again at Naples, and in the company of Alexander von Humboldt and Gay Lussac he had the good fortune to witness Vesuvius in active eruption.

Having explored the most interesting parts in Southern Europe, Von Buch then travelled for two years, 1806-8, in Scandinavia and Lapland. The published account of his travels, *Through Norway and Lapland*, established his fame as a gifted writer and an acute observer. Little had hitherto been known about the climatology and geology of these high European latitudes, and Von Buch contributed data of far-reaching significance. For example, he pointed out that although the rocks in these regions follow the same general scheme of succession as Werner had drawn up, the granite could by no means be regarded as the oldest rock-formation, since he had observed it near Christiania in a position *above* the Transitional Limestone. Again, he showed on mineralogical evidence that many of the erratic blocks scattered over the North German plains must have come from Scandinavia.

Von Buch also examined the raised beaches and terraces of Scandinavia, and came to the conclusion that the Swedish coast was slowly rising above the level of the sea. In this he agreed with the opinion that had been formed by Playfair with regard to the raised beaches of Scotland. On the other hand, Linnæus and Celsius had attributed the fluctuations on the Scandinavian coasts to a sinking of the water-level round the shores.

In 1809 Von Buch was chiefly engaged in mineralogical and geological researches in the Alps. Meanwhile, great

interest had been roused throughout Europe by the results of Von Humboldt's brilliant volcanic studies in Central and South America, and Von Buch determined to make a special study of some volcanic district.

Accompanied by the English botanist, Charles Smith, he visited the Canary Isles, and in 1815 convinced himself that they had been the centre of intense volcanic activity. In his famous monograph, *A Physical Description of the Canary Islands*, published in 1825, he enunciated his hypothesis of upheaval craters, and distinguished between "centres" and "bands" of volcanic action. In 1817 he travelled to Scotland and visited Staffa and the Giant's Causeway. When he again returned to the Alps, he renounced the Wernerian doctrines of the origin of basalt and other volcanic rocks, and ascribed the upheaval of the Alps to the intrusion of igneous rocks. About this time he went to Fassa Valley in South Tyrol, and there he formed a curious volcanic theory in explanation of the dolomitisation of the rocks in that district.

In 1832 Von Buch edited a geological map of Germany, and this magnificent work had already run through five editions in 1843. The last twenty years of his life were for the most part devoted to palæontological studies, and we owe to this period a valuable series of papers on Cephalopods, Brachiopods, and Cystoids; also a comprehensive treatise on the Jurassic formation in Germany, which has been the basis for all future work on this subject. Some part of every year, however, was spent by Von Buch in travelling. He often went to the Alps, and he regularly attended the Scientific Congresses. Most of his Alpine journeys were accomplished on foot. Clad in short breeches, black stockings, and buckled shoes, the pockets of his black coat stuffed with note-books, maps, and geological tools, his tall, imposing figure was bound to command attention. His travelling luggage was limited to a fresh shirt and a pair of silk stockings. His physical endurance was only surpassed by his iron determination, which could overcome all difficulties and discomforts. Socially, he was everywhere beloved; his aristocratic bearing, his mastery of foreign languages, his wide knowledge of science and literature,—all combined to make him one of the most agreeable companions. His independent means placed him in a position of unusual influence. On the one side he enjoyed the friendship and intimacy of his scientific colleagues, and on

the other he moved in the first social circle in Berlin. Men still live who can bear enthusiastic personal testimony to the noble way in which Von Buch exerted this influence for the benefit of science. After a short illness, he died in Berlin on the 4th March, 1852.

Leopold von Buch was rightly regarded as the greatest geologist of his time. He had studied in every domain of geology; he was familiar with a large part of Europe. Wherever he went, he willingly and freely communicated his own knowledge to others, and ever rejoiced to be able to assist by his money or his influence any one in whom he detected a true devotion to science. At the same time he had little patience with men of mediocre ability, and was very severe towards importunity of any kind. His ridicule was feared as much as his praise was valued. He was an acute thinker and wonderful observer, and possessed in a high degree the rare gift of clear and elegant exposition.

A complete edition of his works was published after his death at Berlin (1867-77).

Alexander von Humboldt, the friend and fellow-student of Von Buch, although less illustrious as a geologist, had a more versatile and philosophical turn of mind. Like Von Buch, Humboldt belonged to an old aristocratic family. He was born in Berlin in 1769, studied at first in Göttingen, afterwards in 1791-92 with Werner at Freiberg. On the completion of his studies he was made Director of Mines, and moved from Bayreuth and Ansbach to Steben in the Fichtel mountains. Several papers written by him during this period on "The Magnetic Properties of Serpentine and other Rocks," attracted the attention of mineralogists. In 1793 he visited the salt mines in the Salzkammergut and Galicia, but in 1796 he resigned his Government appointment, to follow out independent lines of research. During the winter of 1797-98, when he and Von Buch lived together in Salzburg, he made a series of observations on meteorology and earth magnetism, and took barometric and trigonometric measurements of height.

In a treatise published in 1799, Von Humboldt endeavoured to explain the tropical climate of earlier geological periods by a combination of the Laplace theory of heat with Werner's views regarding the precipitation of the primitive rock materials from aqueous solutions. And although his treatise is almost forgotten in science, it contains a number of sug-

gestive ideas which were not without their influence in directing subsequent investigation to the causes of great climatological variations.

Humboldt, who was in possession of large private means, now began to make arrangements for a few years of travel on a large scale, and went in May 1798 to Paris. In June 1799, accompanied by the botanist Aimé Bonpland, he set out for Central and South America.

The expedition was undertaken primarily to obtain more knowledge of the physical geography and botany of tropical regions, but Humboldt at the same time devoted a large share of attention to the volcanoes, earthquakes, and geological structure of the New Continent. He said that one of the chief motives of his journey was to test a hypothesis which he had formed—that the older strata composing mountain-systems had a parallel strike. It had struck him during his stay in the Fichtel mountains that the older members in the rock-succession showed always a N.E.–S.W. strike; and he found the same general strike in the Erz mountains, the Salzburg Alps, and the "slate" mountains of the Rhine. He had therefore concluded that all the older rock-formations of the earth strike in N.E.–S.W. direction, and cross the meridians at a constant angle of about 52°.

His observations in Columbia and in the coastal ranges of the Gulf of Mexico led to the same result, and from this agreement he drew the general principle that the strike of the older strata was quite independent of the geographical trend of mountain-systems, and was regulated by a force which took its origin in the original laws of attraction governing terrestrial matter. This principle has, however, proved quite untenable, and is at the present day completely forgotten.

After a short stay in Teneriffe, Humboldt landed at Venezuela, and in November 1799 for the first time witnessed an earthquake at Cumana. He made a detailed study of Venezuela, then spent some time in the Orinoco district, and was in Cuba from December 1800 until March 1801. Afterwards he proceeded to New Granada, Peru, and Ecuador, where he remained until 1803, then worked for a year in Central America. In the summer of 1804 he returned by Havana and North America to Paris. There he became at once absorbed in physical and chemical studies, conducted along with Biot, Gay Lussac, and Arago, and he also com-

menced the publication of his great work, *Travels in the Equinoctial Regions on the New Continent.* This work comprises twenty volumes; but although there were several collaborators, the work was never quite completed, and the expenses in connection with it swallowed up the remainder of Von Humboldt's means. In the spring of 1805 he visited Italy, and with his friends, Gay Lussac and Leopold von Buch, saw an eruption of Vesuvius.

Humboldt's best contributions to geology were his investigation of volcanoes and earthquakes, and the broad generalisations which he drew regarding volcanic action. He concluded his description of American volcanoes with a review of all the volcanic phenomena known to have transpired on the face of the earth, and tried to demonstrate, from a large number of observations, that the subterranean centres of volcanic action are in direct communication with one another. He placed great importance upon the connection of volcanoes and earthquakes on the coasts of the Gulf of Mexico and in the Antilles, where subterranean disturbances were felt almost simultaneously over a district several thousand square miles in extent. Humboldt's account of the catastrophe in the year 1759, which gave birth to the Jorulla and five other mountains, and covered an area of four square miles with a mass of lava, sand, and slag five hundred feet high, still ranks as one of the most noteworthy contributions in the whole literature of volcanoes.

Widespread interest in scientific circles was also attracted by Humboldt's demonstration of an eruptive fissure one hundred and fifty miles from east to west across Central America, upon which stand the volcanic cones of Tuxtla, Orizaba, Puebla, Toluca, Tancitaro, and Colima.

Through the generosity of the King of Prussia, Humboldt was enabled to devote his energies to science. During nearly twenty years' residence in Paris (1808-27) he published the series of papers which form the groundwork of his *Views of Nature*, and also a special geological work entitled *Geognostic Essay on the Trend of the Rocks in the Two Hemispheres* (Paris, 1822). This work practically marked the conclusion of Humboldt's literary activity in geology. Upon his return to his native city of Berlin in 1827, Humboldt embarked upon his gigantic plan of producing a physical description of the world. Twenty years passed before this plan was realised and his famous work, *The Cosmos*, appeared. While the work was in

progress Humboldt led an active life in other directions. In 1827-28 he gave lectures on geography in the University and the Singing Academy. In 1829, accompanied by Gustav Rose and Ehrenberg, he travelled through Asiatic Russia, the Ural mountains, and Siberia to the Altaï mountains. The mineralogical and geological results of this journey were published in an independent work by Humboldt, and in several papers by Rose.

Alexander von Humboldt died at Berlin on the 6th May 1859, in his ninetieth year.

Although many of the geological ideas of the great German scientist were not destined to endure, it is impossible to overrate the value to geographical and geological science of the precedents which he created, and the wide horizons which he disclosed.

What Buffon and Cuvier accomplished for France in attracting the ardent desires of young adherents to the studies of natural science, was accomplished for Germany, after the death of Werner, by the powerful personalities of Leopold von Buch and Alexander von Humboldt.

It is interesting to note that Germany's greatest poet, Wolfgang von Goethe, was one of those who came under the inspiring influence of Werner. Throughout his long life Goethe never lost his interest in mineralogy and geognosy. He wrote several papers on the more popular topics of geognosy, and carried out some detailed researches in the neighbourhood of Karlsbad, Franzensbad, and the Fichtel mountains. While he never could, as a loyal pupil of Werner, look kindly upon the principles of the Plutonists, his critical mind clearly realised that the theories of extreme Neptunists were untenable. In his *Geological Problems* he expressed his disappointment over the absurd contradictions betrayed in the opposing theories, but arrived at no personal decision in favour of either party. Goethe's geological writings were without significance in the progress of the science.

Hutton, Playfair, and Hall.—At a time when Werner was in the zenith of his fame, during those seventies and eighties of the eighteenth century when young geologists were flocking to hear the wisdom from the lips of the prophet of geognosy in Freiberg, a private gentleman, living quietly in Edinburgh, was deliberating and writing a work on the earth's surface that will live for ever in the annals of geology as one of its noblest classics.

James Hutton, the author of the famous *Theory of the Earth*, was the son of a merchant, and was born in Edinburgh on 3rd June 1726. He received an excellent education at the High School and University of his native city. His strong bent for chemical science induced him to select medicine as a profession. He studied at Edinburgh, Paris, and Leyden, and took his degree at Leyden in 1749, but on his return to Scotland he did not follow out his profession. Having inherited an estate in Berwickshire from his father, he went to reside there, and interested himself in agriculture and in chemical and geological pursuits. The success of an industrial undertaking in which he had a share afforded him ample means, and in 1768 he retired to Edinburgh, where he lived with his three sisters. He actively engaged in scientific inquiry, and enjoyed the cultured social intercourse open to him in Edinburgh. The literary fruits of his life in the country include several papers on meteorology and agriculture, and a large philosophical work.

From his early days he had always taken a delight in studying the surface forms and rocks of the earth's crust, and had lost no opportunity of extending his geological knowledge during frequent journeys in Scotland, England, in Northern France, and the Netherlands. On his tours into the neighbourhood of Edinburgh he was often accompanied by his friends, who realised the originality of many of Hutton's views on geological subjects, and begged him to put them into writing. At last Hutton set himself to the work of shaping his ideas into a coherent, comprehensive form, and in 1785 read his paper on the "Theory of the Earth" before the Royal Society of Edinburgh. Three years later it was published in the *Transactions*.

The publication of the work attracted little favourable notice. This may have been due partly to the title, which was the same as that of so many valueless publications, and partly to the involved, unattractive style of writing; in larger measure, however, it was due to the fact that the learning of the schools had no part in Hutton's work. Hutton's thoughts had been borne in upon him direct from nature; for the best part of his life he had conned them, tossed them in his mind, tested them, and sought repeated confirmation in nature before he had even begun to fix them in written words, or cared to think of anything but his own enjoyment of them.

Hutton's work was projected upon a plane half a century beyond the recognised geology of his own time. Hutton's audience of geologists had to grow up under other influences than polemical discussions between Neptunists and Plutonists, and had to learn from Hutton himself how to tap the fountain of science at its living source.

In 1793 a Dublin mineralogist, Kirwan, attacked Hutton's work in ignoble terms, and the great Scotsman, now advanced in years, resolutely determined to revise his work and do his best by it. Valuable additions were made, and the subject-matter brought under more skilful treatment. In 1795 the revised work appeared at Edinburgh, in independent form and in two volumes. It was his last effort. Hutton died in 1797 from an internal disease which had overshadowed the closing years of his life.

The original treatise of Hutton is divided into four parts. The first two parts discuss the origin of rocks. The earth is described as a firm body, enveloped in a mantle of water and atmosphere, and which has been exposed during immeasurable periods of time to constant change in its surface conformation. The events of past geologic ages can be most satisfactorily predicted from a careful examination of present conditions and processes. The earth's crust, as far as it is open to our investigation, is largely composed of sandstones, clays, pebble deposits, and limestones that have accumulated on the bed of the ocean. The limestones represent the aggregated shells and remains of marine organisms, while the other deposits represent fragmental material transported from the continents. In addition to these sedimentary deposits of secondary origin there are *primary* rocks, such as granite and porphyry, which, as a rule, underlie the aqueous deposits.

In earlier periods the earth presented the aspect of an immense ocean, surmounted here and there by islands and continents of primary rock. There must have been some powerful agency that converted the loose deposits into solid rock, and elevated the consolidated sediments above the level of the sea to form new islands and continents.

According to Hutton, this agency could only have been heat; it could not have been water, since the cement material (quartz, felspar, fluorine, etc.) of many sedimentary rocks is not readily soluble in water, and could scarcely have been provided by water. On the other hand, most solid rocks

are intermingled with siliceous, bituminous, or other material which may be melted under the influence of heat. This suggested to Hutton his theory that at a certain depth the sedimentary deposits are melted by the heat to which they are subjected, but that the tremendous weight of the superincumbent water causes the mineral elements to consolidate once more into coherent rock-masses. He applied this theory of the melting and subsequent consolidation of rock-material universally, to all pelagic and terrestrial sediments.

In the third part it is shown that the present land-areas of the globe are composed of rock-strata which have consolidated during past ages in the bed of the ocean. These are said to have been pushed upward by the expansive force of heat, while the strata have been bent and tilted during the upheaval. Hutton next describes the occurrence of crust-fissures both during the consolidation of the rock and during the elevation of large areas, and the subsequent inrush of molten rock or mineral ores into the fissures. He regards volcanoes as safety-valves during upheaval, which by affording exit at the surface for the molten rock-magma and superheated vapours prevent the expansive forces from raising the continents too far.

The evidences of volcanic eruption in the older geological epochs are next discussed. Hutton expresses the opinion that during the earlier eruptions the molten rock-material spread out between the accumulated sediments or filled crust-fissures, but did not actually escape at the surface; consequently, that the older rock-magmas had solidified at great depths in the crust and under enormous pressure of superincumbent rocks. He calls the older eruptive rocks "*subterraneous lavas*," and includes amongst them porphyry and the whinstones (eq. trap-rock, greenstone, basalt, wacke, amygdaloidal rocks); granite was also added in a later treatise. Hutton points out that the subterraneous lavas have a crystalline structure, whereas those that solidify at the surface have a slaggy or vesicular structure.

In the fourth part, Hutton concentrates attention on the pre-existence of older continents and islands from which the materials composing more recent land areas must have been derived. He likewise discusses the evidences of pre-existing pelagic, littoral, and terrestrial faunas from which existing faunas must have sprung. But, he continues, the existence of

ancient faunas assumes an abundant vegetation, and direct evidence of extinct floras is presented in the coal and bituminous deposits of the Carboniferous and other epochs. Other evidence is afforded in the silicified trunks of trees that occasionally are found in marine deposits, and have clearly been swept into the sea from adjacent lands.

Hutton then sets forth, in passages that have become classic in geological science, the slow processes of the subaerial denudation of land-surfaces. He describes the effects of atmospheric weathering, of chemical decomposition of the rocks, of their demolition by various causes, and the constant attrition of the soil by the chemical and mechanical action of water. He elucidates with convincing clearness the destructive physical, chemical, and mechanical agencies that effect the dissolution of rocks, the work of running water in transporting the worn material from the land to the ocean, the steady subsidence of coarser and finer detritus that goes on in seas and oceans, lakes and rivers, and the slow accumulation of the deposits to form rock-strata. Hutton impresses upon his readers the vastness of the geological æons necessary for the completion of any such cycle of destruction and construction. In proof of this, he calls attention to the comparative insignificance of any changes that have taken place in the surface conformation of the globe within historic time.

Hutton was thus the great founder of physical and dynamical geology; he for the first time established the essential correlation in the processes of denudation and deposition; he showed how, in proportion as an old continent is worn away, the materials for a new continent are being provided, how the deposits rise anew from the bed of the ocean, and another land replaces the old in the eternal economy of nature. The outcome of Hutton's argument is expressed in his words "that we find no vestige of a beginning,—no prospect of an end."

When we compare Hutton's theory of the earth's structure with that of Werner and other contemporary or older writers, the great feature which distinguishes it and marks its superiority is the strict inductive method applied throughout. Every conclusion is based upon observed data that are carefully enumerated, no supernatural or unknown forces are resorted to, and the events and changes of past epochs are explained from analogy with the phenomena of the present age.

The undeveloped state of physics and chemistry in the time

of Hutton certainly gave rise to several errors in connection with the origin of minerals and rocks. No geologist now would agree with the principle that heat has hardened and partially melted all sedimentary rocks, and just as little would he ascribe to heat the origin of flint, agate, silicified wood, etc. On the other hand, the recognised hypothesis of regional metamorphism of the crystalline schists is an extension of Hutton's conception of the action of heat and pressure upon rocks.

Hutton was the first to demonstrate the connection of eruptive veins and dykes with deeper-seated eruptive masses of granite, and the first to point out the differences of structure between superficial lavas and molten rock solidified under great pressure. In assuming that granite represents rock consolidated from a molten magma, Hutton laid the foundation of the doctrines of Plutonism as opposed to those of Neptunism.

Again, no one before Hutton had demonstrated so effectively and conclusively that geology had to reckon with immeasurably long epochs, and that natural forces which may appear small can, if they act during long periods of time, produce effects just as great as those that result from sudden catastrophes of short duration.

Hutton's explanation of the uprising of continents, owing to the expansive force of the subterranean heat, was not altogether new, nor was it satisfactory. Neither had Hutton any clear conception of the significance of fossils as affording evidence of a gradual evolution in creation. Yet in spite of these disadvantages, Hutton's *Theory of the Earth* is one of the masterpieces in the history of geology. Many of his ideas have been adopted and extended by later geologists, more particularly by Charles Lyell, and form the very groundwork of modern geology. Hutton's genius first gave to geology the conception of calm, inexorable nature working little by little—by the raindrop, by the stream, by insidious decay, by slow waste, by the life and death of all organised creatures,—and eventually accomplishing surface transformations on a scale more gigantic than was ever imagined in the philosophy of the ancients or the learning of the Schools. And it is not too much to say that the Huttonian principle of the value of small increments of change has had a beneficial, suggestive, and far-reaching influence not only on geology but on all the natural sciences. The generation after Hutton applied it to palæontology, and

thus paved the way for Darwin's still broader, biological conceptions upon the same basis.

Hutton's scientific spirit and genial personality won for him many friends and adherents amongst the members of the Edinburgh academy. The most distinguished of these were Sir James Hall and the mathematician John Playfair. Hall (1762-1831) contested the validity of the opinion held by some of Hutton's opponents, that the melting of crystalline rocks would only yield amorphous glassy masses. Hall followed experimental methods; he selected different varieties of ancient basalt and lavas from Vesuvius and Etna, reduced them to a molten state, and allowed them to cool. At first he arrived only at negative results, as vitreous masses were produced; but he then retarded the process of cooling, and actually succeeded in obtaining solid, crystalline rock-material (*Nicholson's Journal*, No. 38, 1800). By regulating the temperature and the time allowed for the cooling and consolidation, Hall could produce rocks varying from finely to coarsely crystalline structure. And he therefore proved that under certain conditions crystalline rock could, as Hutton had said, be produced by the cooling of molten rock-magma. Hall then put to the test Hutton's further hypothesis, that limestone also was melted and re-crystallised in nature. To this hypothesis the objection had been made that the carbonic acid gas must escape if limestone were brought to a glowing heat, and the material would be converted into quicklime. This was Hall's first experience; then he devised another experiment. He introduced chalk or powdered limestone into porcelain tubes or barrels, sealed them, and brought them to a very high temperature. The carbon dioxide gas could not escape under these conditions. The calcareous material was thus subjected to the enormous pressure of the imprisoned air, and carbonic acid was converted under this pressure into a granular substance resembling marble. Hall calculated from a series of successful experiments that a pressure equivalent to fifty-two atmospheres, or to a depth of sea-water 1,700 feet below sea-level, was necessary for the production of solid limestone, 3000 feet of depth for that of marble, and 5,700 feet of depth in order to reduce carbonate of lime to a molten state.

These results were afterwards confirmed by other experimentalists. Thus Werner's theory that crystalline rock represented in all cases a precipitate from water was shown to be

inadequate, and it was incontestably proved that crystalline rock might originate from molten rock when slowly cooled under pressure.

Hall also conducted experiments on the bending and folding of rocks. He spread out alternate horizontal layers of cloth and clay, placed a weight upon them, and subjected them to strong lateral pressure. These and similar experiments have been often repeated within recent years, and it is well known that in this way phenomena of deformation can be artificially produced which bear the closest resemblance to the phenomena of rock-deformation under natural conditions.

Hall, in his desire to vindicate Hutton's theory, became himself one of the great founders of experimental geology. At the same time, John Playfair,[1] whose interest in geology had been roused by Hutton's companionship, became the enthusiastic exponent of Hutton's theory.

It was Playfair's literary skill that opened the eyes of scientific men to the heritage Hutton had left for them. He did for Hutton's teaching what fifty years after was done for Darwin's doctrines by the gifted Huxley. The brilliant exponent and successful combatant, no less than the deep student and enlightened thinker, is required to establish a new system of thought, for such a system is always bound to be in a measure reactionary to older doctrines that have received the stamp of usage and authority.

Playfair's *Illustration of the Huttonian Theory* (1802) is a lucid exposition of that theory in the form of twenty-six ample discussive notes. Playfair's work differs in no essential point from the views held by his master and friend, but many subjects which receive a subordinate treatment in the *Theory of the Earth* are brought into prominence by Playfair, and placed for the first time on a firm scientific basis.

Among the subjects fully discussed are the uprise and bending of strata, the origin of crystalline rocks at low

[1] John Playfair, born 1748, in Bervie, Forfarshire, son of a minister, showed in his early years a remarkable genius for mathematics. He studied in Aberdeen and Edinburgh, in 1773 became minister in Bervie, in 1785 Professor of Mathematics in the University of Edinburgh, and twenty years after Professor of Philosophy in the same University. Led by Hutton into the study of geology, he devoted his holidays to geological tours throughout Great Britain and Ireland, and in 1815 and 1816 made longer tours to Auvergne, Switzerland, and Italy; he died in 1819 in Edinburgh.

horizons of the crust and under very great pressure, and the occurrence of granite as dykes in various British localities. His treatment of valley and lake erosion is extremely able. And Playfair was the first geologist who realised that *the huge erratic blocks might have been carried to their present position by former glaciers.* His insight in this respect would alone have won for him a lasting fame, for the erratics on Alpine slopes and plains had long been observed by geologists and an explanation vainly sought. Playfair also studied the raised beaches on the coast-line of Scotland, and rightly concluded that they afforded evidence of an actual uprise of the land, in opposition to the views of Linnæus and Celsius, who had explained a similar series of phenomena in Sweden as a result of the retreat of the ocean. Playfair gave the first complete account of the evidences of oscillations of level in European lands.

Playfair's style is a model of clearness and precision, and his arguments are always thoroughly logical, and in agreement with physical laws. His *Huttonian Theory* was translated into French by C. A. Basset in 1815.

Theories of the Earth's Origin proposed by De Luc, De la Métherie, Breislak, Kant, Laplace, and others.—Although Hutton had enunciated his theory of the earth without introducing any personal element, it was a foregone conclusion that a doctrine which undermined the whole foundation of Werner's Neptunian teaching, was bound to meet with adverse criticism. Mention has already been made of the attacks made by Kirwan, Professor of Mineralogy in Dublin (*Geological Essays*, 1799). His arguments are based upon chemical and physical objections to Hutton's theory, and culminate in a bitter denunciation of a theory inimical to religion, and at variance with the Mosaic account, inasmuch as it demanded immeasurable epochs in place of the Biblical chronology, and even denied the universal deluge, to which Kirwan mainly ascribed the present configuration of the earth.

Another antagonist of Hutton's theory was the versatile Jean André de Luc, a Genevese by birth, who came into public notice during the political struggles in Geneva in the middle of the last century, and afterwards attained to a favoured position in the court of Queen Charlotte of England. De Luc wrote on all manner of scientific subjects, and his

great desire was to bring the facts of science into complete and unquestionable harmony with the words of Holy Writ.

A special interest is attached to De Luc's *Letters on some parts of Switzerland*, which were originally addressed to Queen Charlotte, and were afterwards published in 1778. In the preface to these letters he proposes the term *Geology* as the most suitable for a scientific study purporting to deal with the history of the earth. The preface is written in bombastic style, announcing that a new outline of cosmology and geology would be enunciated by the writer. The *Letters* themselves contain little that could be supposed to bear out the high promises of the preface, but a year later De Luc's theory appeared in a work of five volumes, entitled *Physical and Moral Letters on the History of the Earth and of Man.* The moral discourses are comprised in the first part of the work. Then the scientific letters begin with a *résumé* of the theories of the earth's origin constructed by Burnet, Whiston, Woodward, Leibnitz, Scheuchzer, and others, all of which are found erroneous and set aside by De Luc. He then describes his travels in different parts of Europe, and records any geological observations he had made.

He states his reasons for disbelieving in the enormous erosive activity which contemporaneous writers ascribed to water. And he strongly expresses himself in favour of the eruptive origin of basalt, as against the ideas held by Werner's school. The fifth volume is that in which De Luc unfolds his own theory. He distinguishes *primordial mountains*—composed of rocks of unknown origin, such as granite, schist, serpentine, quartzite—from *secondary mountains*, composed of stratified deposits containing fossils, and clearly of aqueous origin. As there are terrestrial plants and animals among the fossils of the "secondary mountains," De Luc supposes that, although the ocean must have originally covered the earth's surface, there must have been land areas at the time when the strata of the "secondary mountains" were deposited. The floor of this restricted ocean was, he said, formed by the "primordial mountains," but in the heart of these mountains there were cavities of irregular shape disposed tier upon tier above one another, so that the firm rock merely formed a scaffolding. Owing to subterranean fire or any other disturbing cause, it sometimes happened that the rock pillars in these hollow areas gave way, and crust-inthrows ensued. The

increasing weight of the deposits, which were accumulating on the ocean-floor, as well as the pressure caused by the repeated crust-inthrows, at last caused the collapse of the lower tiers. The sea-water rushed in to fill the depressed areas, and the level of the ocean sank. This was called the first revolution in De Luc's sequence of creative events. As the ocean sank, the present continents and islands made their appearance; plant seeds from the old continents were washed on the strands of the emerging lands, and soon a rich vegetation appeared. The fauna of the primitive ocean and lands in some cases left descendants to people the new oceans and lands, in other cases became extinct.

The bones of the large tropical mammalia found in the superficial strata of northern areas in the present continents were believed by De Luc to be the transported remains of extinct forms that had inhabited the older continents. According to De Luc, all known facts led to the conclusion that the new continents, and generally the present configuration of the earth, came into existence not more than 4000 years ago.

Four letters protesting against both Hutton and Playfair were reprinted in a diffuse work by De Luc, entitled *Elementary Treatise of Geology.* A large number of papers were contributed to journals by De Luc; but although he was a man who was held in high respect and favour during his lifetime, his papers have no permanent place in literature, and his attacks on the great Scottish geologists were absolutely without effect.

Like De Luc, the Parisian mineralogist and physician, De la Métherie, enjoyed considerable popularity among his contemporaries. His chief work, published at Paris in 1791, bore again the title *Théorie de la Terre.* De la Métherie's work was founded for the most part on Werner's teaching. Many of the erroneous notions in De Maillet's *Telliamed* were revived and new speculations attempted, but without any basis of observation. According to De la Métherie, all mountains, valleys, and plains took origin from the precipitation of crystals in a primeval ocean which covered the whole earth, and was of enormous depth. During the accumulation of rock-precipitates certain large subterranean cavities filled with air or vapour remained free from solid deposits. As the total volume of water diminished, a considerable portion of the

sea withdrew into these crust-cavities, and at the same time the areas of denser precipitation became land. Volcanic eruptions invariably originated in these primitive air and vapour chambers in the earth's crust, which were moreover frequently connected with one another by crust-fissures.

It is unnecessary to enter into the further details of De la Métherie's *Theory*. Two years after its publication, Bertrand, another French geologist, wrote *New Principles of Geology*, a work contesting De la Métherie's conceptions, but not in itself contributing any new facts of value to science. Ballenstedt, a German pastor, was the author of a book entitled *Die Urwelt* (or the *Primeval World*), which was widely read in scientific and literary circles. It endeavoured to "expound the Biblical stories in a sensible way," and went so far as to affirm that all human races had not descended from the one pair in Paradise, but that there had been originally several well-defined human species.

Scipio Breislak (1748-1826), an Italian, deserves to be remembered for his determined opposition to the Neptunian doctrines. In his *Text-book of Geology* he tries to demonstrate that the earth was originally in a fluid state, but that the volume of water now present on the globe would be absolutely insufficient to dissolve the solid material of the crust.

Further, the presence in earlier epochs of a much greater volume of water was a mere hypothesis, so also was the conception of internal crust-cavities into which large quantities of water might have withdrawn after the separation of the rock-precipitates. Again, there was no positive evidence that the surface of the ocean had sunk. The cases of apparent retreat of the sea from the coasts of Scandinavia, or in the Gulf of Naples, might be just as well explained by oscillatory movements of the earth's crust as by the supposed general lowering of the sea-level. After Breislak had demonstrated the impossibility of a fluid state of the earth with water as the solvent, he tried to prove that the primitive fluidity of earth substances had been due to their intimate admixture and combination with heat-particles. Breislak imagines the earth in its first periods of formation as a confused cosmic mass soaked in heated matter, and therefore more or less molten. Two modes of heat are distinguished by Breislak, *free* heat, which calls forth the sensation of heat, and *combined* heat, which is not perceptible to the senses, but whose combination

with other forms of matter effects important changes. Upon this physical basis, Breislak supposes that, as the heat-particles entered into combination with other particles of matter for which they had affinity, the total amount of free heat diminished, and the temperature of the earth perceptibly cooled. Gaseous material gathered internally and still more at the surface, where it was condensed as a primitive ocean. The internal gases in combination with heat produced elastic vapours. These tried to force their way to the surface, cracking and breaking the solid crust that had begun to form.

Breislak then discusses the origin of the various kinds of crystalline rock found in the crust. He disagrees with Hutton's explanation of gneiss and crystalline schist as altered sedimentary rock, and includes them together with granite, porphyry, and other igneous rocks, as products of the cooling of matter from the primitive molten state. Breislak's ideas about rock-structure soon fell into oblivion, but his able criticism of the Neptunian dogmas was largely instrumental in eradicating them from the teaching of the universities and colleges. There would be little profit in recording further the many contradictory theories of the earth that appeared between the publication of Buffon's *Théorie de la Terre* in 1749 and of Breislak's *Introduzione alla Geologia* in 1811. What seems very remarkable is that in none of these can we trace the influence of the cosmogony and geogeny made known in 1755 by the great philosopher, Immanuel Kant, in his *Naturgeschichte des Himmels*. Neither do geologists seem to have benefited by the kindred work of the French mathematician, Laplace, *Exposition du Système du Monde*, published in 1796.

Kant's little book appeared anonymously, immediately before the outbreak of the Seven Years' War. It received no attention, was forgotten, and ninety years elapsed before Alexander von Humboldt unearthed it from neglect. Kant originated the conception that the ordered cosmical universe might have been produced merely by the agency of mechanical forces acting upon a vaporous chaotic mass. Kant supposed that all the matter composing the spherical bodies of our solar system, the planets and the comets, was in the beginning broken up into its elementary constituents and distributed throughout space. All the particles of matter could attract and repel one

another; the equilibrium of matter was in a highly fickle and unstable condition. The denser particles of matter tended, by reason of their attractive force, to unite into a central body. At the impact the particles were diverted by the disturbing action of the attractive and repulsive forces; there arose numerous whirls of movement crossing one another. The particles in these whirls or vortices originally moved in all directions, and were constantly coming into conflict with one another, but finally the movements became uniform in direction, and the particles revolved almost in one heavenly plane, and without mutual disturbance in concentric circles round the sun. Within each individual ring the attraction of the particles again came into play, aggregates of the denser particles attracted the lighter particles in the same ring until a planetary body formed, revolving round the sun along its particular path. In this way the whole planetary system, including moons and comets, was thought by Kant to have taken origin in order according to the distance of the path of revolution from the sun; first, the planets next the sun, then those more remote from the sun.

While Kant's mechanical theory of the universe explains the origin of all the bodies in the solar system upon the same fundamental principle, it yields no exact information regarding the constitution and the temperature of the sun and the planets. The nebular theory of Laplace, which was founded quite independently of Kant, goes further in this respect, and has therefore come into closer relationship with geology.

Laplace shows that all the planets in the solar system move round the sun from west to east in almost the same plane, that all moons move in similar direction round their planets, and that the sun rotates, so far as is known, in the same direction round its own axis. In the opinion of the great mathematician, a phenomenon so remarkable cannot be mere chance, but indicates some general cause or combination of causes that has determined all those movements. Clearly, there was a time when the planetary spaces now empty were uniformly filled with matter at a high temperature, representing the substances of the planets and moons in the finest state of rarefaction, and having a rotating movement from west to east. A central body, the sun, massed itself in the midst of this vaporous material.

The finely divided mass behaved like a gigantic atmosphere,

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in which equilibrium was sustained by centrifugal force and gravity. As the glowing mass became denser the centrifugal force increased, and peripheral rings of vapour similar to those of Saturn separated from the main body. The detached rings continued to move with the same rate and direction of motion as before. Not being of uniform density, they became rent, the different masses formed themselves into rotating spheres, the larger bodies absorbed a part of the smaller, and thus the planets and their satellites took origin.

The condensation of the vaporous material during the process of aggregation of the particles into spheroids set free a large amount of heat and the newly-formed bodies were raised to a very high temperature; they became radiant masses, radiating light and heat into surrounding space. Owing to the loss of heat by radiation, the surface cooled and shrivelled, and finally a superficial crust formed, at first glowing, afterwards darkening down to its present state.

According to Laplace, the zodiacal light represents certain volatile unconsolidated parts of the solar atmosphere that still surround the sun; while the comets are regarded by Laplace as foreign to the solar atmosphere, belonging probably to the infinite space beyond.

The nebular theory of Kant and Laplace was in far better agreement with the laws of mechanics and the observations of astronomy than any previous cosmogonetic hypothesis. It also helped greatly to elucidate the earliest beginnings of the earth, and was welcomed by geologists. Clearly it brought confirmation to Volcanistic doctrines, and militated against the Neptunian teaching that the primitive crystalline rocks were of aqueous origin.

Local Geognostic Descriptions and Stratigraphy.—A. *Germany.*—The revolutionary tendency of the empirical methods taught by Werner in his system of geognosy is displayed in the numerous local monographs that began to appear in all parts of Europe. Both in mineralogy and in stratigraphy, the chief contingent of new work came from the Wernerian school.

Georg Lasius (1752-1833), who for a long time held the post of Director of the Survey Department in Oldenburg, was no Wernerian, but he contributed a work on the Harz district that ranks among the best and most careful local descriptions of his time. While Lasius was an officer in the Hanoverian

Engineer Corps, the duty of preparing the topographical map of the Harz was entrusted to him. From this beginning, Lasius became interested in the structural relations, and prepared a work which was published in two volumes, *Observations on the Harz Mountains*, together with a petrographical map and a section (Hanover, 1789).

In the first volume, Lasius describes the "primitive rocks" (*Ur-gebirge*) and the "vein-series" (*Gang-gebirge*), and places these groups in contradistinction to the "Flötz formations" or younger stratified deposits. The "vein-series" comprises marine limestones with corals, orthoceratites, bivalves, and gastropods; slates, greywackes, and sandstones; trap-rock, porphyry, and serpentine. The distribution of the various kinds of rock is entered with great accuracy upon a coloured petrographical map, and the term *greywacke* is used for the first time in the literature for a sandstone made up of finely fragmental granite *débris*.

Lasius follows Lehmann for the most part in his sub-divisions of the Flötz deposits; he shows, however, that a part of the porphyry occurs in association with the Red Sandstones of Permian age, and must therefore be younger than the main body of the vein series.

The second volume of the work is devoted to a description of the ores and minerals in the Harz mountains, and contains many new and valuable observations.

The Thuringian Forest was made the subject of several excellent geological works by an eminent scholar of Werner, Johann Karl Wilhelm Voigt (1752-1821). Trained for the law, Voigt gave up this profession, became an ardent geologist, and held the post of Councillor of Mines at Ilmenau in Thuringia.

Voigt's work, in two volumes, entitled *Mineralogical Journey through the Duchy of Weimar and Eisenach*, was published between 1781 and 1785. Like many of his contemporaries, Voigt wrote this work in the form of letters. It contained what was at the time rather exceptional, a series of geological sections. Another work, which was undertaken by Voigt at the desire of Bishop Henry, gives a mineralogical description of the district around the monastery of Fuld. The basalt and phonolite rocks in the neighbourhood are accurately entered in a coloured geological map, and the text is remarkable for Voigt's tacit renunciation of Werner's views about the origin

of these rocks, and his clear exposition of their volcanic nature.

After the publication in 1788 of Werner's work on the occurrence of basalt at the Scheibenberg Hill, the difference of opinion between these two geologists began to assume a more personal aspect, and unfortunately ended in a rupture of their friendship.

Voigt published several important papers on the geology of Thuringia in later years, chiefly in mineralogical journals, and he was also the author of the first practical *Text-book of Geognosy* (Weimar, 1792). In the description of the rocks and the order of rock-formations in the crust, Voigt follows Werner's teaching, but he has a more just appreciation of the causes of volcanic phenomena and the origin of volcanic rocks.

His last large work was entitled *Attempt at a History of Coal, Brown Coal and Turf* (Weimar, 1802-5). This contains, in addition to the geological data, practical advice on the determination of workable coal-seams, and the industrial uses of the various kinds of combustible deposits.

A detailed account of several localities in the Thuringian Forest was also given by Johann Ludwig Heim, a Privy Councillor in the Duchy of Meiningen. Heim (1741-1819) was tutor to the Princes of Meiningen, and during occasional journeys he made a large mineralogical collection, and wrote a number of papers compiled into one larger work, *Geological Descriptions of the Thuringian Forest* (Meiningen, 1796-1812). These are distinguished by the independence of his views, acute powers of observation, and his clear descriptions; but there is no geological map, and the stratigraphical details are only illustrated by rough sketches. Hence the work, careful though it was, never received much recognition, and was much less instructive in character than that of Voigt.

Heim referred the origin of the primitive rocks to chemical crystallisation from an indefinite mixture or "fluidum," possibly gaseous in constitution. He allowed that the slates and greywackes ("transitional rocks" of Werner) might have been precipitated from a watery fluid, but he thought it impossible to trace any difference in the ages of the various precipitates. His idea was that all these rocks are arranged in the crust as spherical or elliptical masses whose kernel is

composed of granite, and whose outer layers comprise porphyry and the primitive rocks. This crude conception of Heim's has certain points of analogy with the much later theory of "central massives" promulgated by mountain geologists.

Heim sub-divided the sedimentary or stratified deposits in four main groups as follows:—

4. Newer limestone, including Muschelkalk and Jurassic limestones.
3. "Bunter" or variegated sandstone (including the sandstone of Füchsel).
2. Older limestone or Upper Dyas ("Zechstein" of Lehmann).
1. Red Underlyer or Lower Dyas ("Rothe Todtliegende" of Lehmann).

He also made a special inquiry into the origin and distribution of basalt, and wrote strongly in favour of its eruptive origin. He regarded it as younger than all four sub-divisions of the sedimentary deposits, and supposed that its eruption had been accompanied by violent crust-movements, during which the rocks were bent and fractured and the mountain-systems were upheaved.

The subjects of denudation and erosion also attracted Heim's attention, and he gave a full description of the erosion of valleys by the agency of running water, enumerating many good examples in confirmation of his ideas ("On the Formation of Valleys," *Voigt's Magazine*, 1791).

One of the most loyal and gifted of Werner's scholars was Johann Karl Freiesleben (1774-1846). He was born and educated at Freiberg, and enjoyed the intimate companionship of his master and patron. While attending Werner's classes he formed the friendship of Von Humboldt, Von Buch, and Von Schlotheim; he afterwards travelled with Buch in Saxony, with Schlotheim in Thuringia, and with Humboldt in the Bohemian mountains, the Alps, and the Swiss Jura mountains.

His first large work, *Description of the Harz Mountains* (2 vols., 1799), contains chiefly mineralogical and technical information, and a later work, *Contributions to the Mineralogical Knowledge of Saxony*, published in 1817, is of the same nature.

As a geologist, Freiesleben accomplished memorable work

in his study of the sedimentary series on the northern slopes of the Thuringian Forest. His comprehensive work, *Geognostic Contribution to the Knowledge of the Copper Slate Series, with special reference to a part of Mansfeld and Thuringia* (Freiberg, 1807-15, in 4 vols., and with coloured geognostic map), still ranks as one of the most accurate local monographs on the geology of North Germany. It depicts the different deposits according to their mineralogical character, their stratigraphical succession, their cartographical distribution, and the occurrences of fossils and minerals, in a manner so exhaustive, that later authors have been able to add little to his results.

Freiesleben included under the term copper-slate or ore-bearing series the strata from the "Red Underlyer" to the "Muschelkalk" inclusive; in other words, all the sub-divisions now placed in the Dyassic and Triassic geological systems were treated by him as belonging to one great formation.

While the Thuringian Forest and the Harz mountains received by far the largest share of attention from the early geologists, certain other parts of North Germany also found their way into geological literature. The neighbourhood of Hildesheim was made the subject of research papers by J. H. S. Langer in 1789, and again by J. A. Cramer in 1792. A paper entitled "Physical and Mineralogical Observations on the Mountains of Silesia," by A. Gerhard, appeared in the *Reports of the Royal Academy of Berlin* in 1771; and in 1795 the mineralogist, D. L. G. Karsten, published a geognostic account of a journey in Silesia. Still more widely read were Leopold von Buch's writings on Silesian districts. His *Attempt at a Geognostic Description of Silesia*, which he dedicated to Professor Werner, is accompanied by a coloured general map. This paper, like Von Buch's earlier paper on the district of Landeck, is more concerned with petrographical than with geological details, yet it affords a good general survey of the geological structure of a territory previously little investigated.

An individual charm is lent to this and to all the subsequent works of Leopold von Buch by his skilful delineation of the relations between the geological structure and the superficial aspects of a country. A landscape appealed to his artistic sense as well as to his scientific interest, and his mastery of language enabled him to transfer his impressions picturesquely in writing. Mineralogical descriptions were fully given; but

from the dry details his mind would sweep with easy relief to the consideration of the broader truths of the science.

The following passage may be quoted as an example of Von Buch's style of writing. It describes his idea of the origin of the Carboniferous series of rocks:—"First the conglomerate falls, a mixture of great stones that could not be carried far from their parent mass, even by an angry flood; and they tear away with themselves the mantle of vegetation which had formerly reposed in security upon their surface. Woods are overthrown, buried beneath the irresistible rush of jagged and broken rock, again and again the floods rise and pour over the land, renewing this drama of destruction. Countless fragments are rolled from the heights into the narrow mountain basins and valleys; there in the hollow they are dashed against one another, gyrated and rounded into pebble form. After the surface has been denuded of its vegetation and the force of the flood diminishes, the finer, lighter grains begin to subside and the newer fine-grained sandstone accumulates."

Von Buch was particularly interested in the conglomerates, and on the basis of the lithological features he traced the pebbles and larger fragments included in the conglomerates very carefully to their place of origin. He demonstrated that the pebbles are smaller the more remote they are from the rock from which they have been broken, and by comparative studies he tried to determine the direction that had been followed by the transporting floods.

From a strictly scientific point of view, Leopold von Buch's geological researches were less successful than those of Voigt or Freiesleben, which marked a distinct note of advance in stratigraphical inquiry. The geological data given by Von Buch in his Silesian papers are sketchy in comparison, and there is no serious effort to draw up a definite succession of the rock deposits upon either stratigraphical or palæontological grounds.

During his Norwegian journey, Leopold von Buch had drawn attention to the position of granite *above* the "transitional" limestone in the neighbourhood of Christiania. Soon after, in 1811, a work on the *Syenite Formation in the Erz Mountains*, written by Raumer and Engelhardt, aroused great interest. These authors stated that the granite and syenite on the north-east edge of the Erz

mountains were not, as Werner had supposed, the oldest rocks, since they rested locally upon the gneiss and schist series, and even upon the strata of the "transitional" series. Similar observations had been made by these authors in the Harz mountains, and corroborative reports began to appear in other countries disproving the commonly accepted dogma that all occurrences of granite must of necessity be of the highest antiquity.

In comparison with Middle and North Germany, geognostic research was very backward in South and West Germany, notwithstanding the fact that these areas are particularly rich in fossils, and have in later times very materially assisted in developing our knowledge of past epochs.

The first to examine the rocks of the Old Bavarian provinces was Mathias von Flurl (1756-1823). At the age of twenty-four Flurl was elected Professor of Physics and Natural History in the Industrial Academy at Munich; afterwards he studied for a time under Werner. On his return to Bavaria, he was advanced from one position to another, and from the year 1800 occupied the post of Director of Mines. His chief work, *A Description of the Mountains of Bavaria and the Upper Pfalz*, was written in the form of letters. Pre-eminence was given to matters concerning mines and metallurgy; at the same time, he related in simple narrative style what he had seen of any geological interest in the course of his travels, mentioned the localities where fossils occur, and noted the surface distribution of different kinds of rock. But Flurl avoided all reference to debatable points, such as the order of the succession of rocks, the relative age of fossils, or the mode of origin of the rocks. The work was accompanied by a small general map of Bavaria, wherein a few of the leading varieties of rock were distinguished—granite, gneiss, schist, limestone, sandstone, nagelflue, and alluvium.

Flurl was thus the pioneer of geology in Old Bavaria, and his work has a permanent value on account of its reliable and varied information. On the other hand, it cannot be placed on the same scientific platform as the more special contributions to geology made by his contemporaries in Northern Germany.

B. *Austria-Hungary and the Alps.*—A foundation had been constructed for the geological investigation of Austria-Hungary

by Ferber's important series of works,—his *Treatise on the Mountains of Hungary*, his *Account of Travels*, and his *Contributions to the Mineralogy of Bohemia* (Berlin, 1774). Twenty years later, another descriptive work on the minerals of Bohemia was contributed by Franz Ambros Reuss, a mineralogist and physician resident in Bilin. The same author wrote a *Text-book of Mineralogy* that had a wide circulation. A pupil of Werner's, Reuss treated the basalts of North Bohemia as rocks of aqueous origin.

The most gifted of the early stratigraphers was Johann Ehrenreich von Fichtel (1732-95), a Hungarian by birth, whose researches in Transylvania were published in 1780; a later work on the Carpathian mountains appeared in 1791. The first volume of Fichtel's *Mineralogy of Transylvania* contains much valuable information about local occurrences of Tertiary fossils in the low range of hills in front of the Transylvanian Alps. In the second volume, Fichtel describes the massive accumulations of rock-salt in Transylvania, and gives an exhaustive technical account of the whole mining industry in Transylvania, the Carpathians, and Galicia. A topographical map shows the distribution of rock-salt in these areas.

Local stratigraphical relations are now and then elucidated, and the origin of the different kinds of rock is discussed, Fichtel declaring himself to be a thorough Volcanist. Amongst rocks of igneous origin Fichtel includes the granite composing the highest mountains, and the gneiss, schist, limestone, and metalliferous rock (rhyolite, dacite, trachyte) composing the mountains of intermediate height; the rocks composing the lower ranges in front of the middle and main chain are, he says, of pelagic origin, and include sand, clay, and pebble deposits. According to Fichtel, rock-salt originated by the evaporation of a fluid mixture of salt and rock-oil, which had sapped into huge crust-cavities after the cooling and consolidation of the earth's crust. Such cavities, with their saline intercalations, form, he says, the heart of the Carpathian mountains.

Fichtel's later work is devoted chiefly to a careful enumeration and description of the eruptive rocks in the Carpathians. He distinguishes *volcanic outbreaks*, with which superficial lava flows are associated, from *volcanic upheavals*, in the course of which wide regions are affected, and masses of igneous material are intruded in the crust.

It can be easily understood that Fichtel's work met with an

incredulous reception by Werner and his adherents. One of those, Jens Esmarch, afterwards Professor of Geology in the University of Christiania, travelled through the districts which Fichtel had described. In all the localities where Fichtel had found evidence of the *igneous* as opposed to the *aqueous* origin of the primitive rocks, Esmarch could see only a confirmation of Werner's teaching (*Short Description of a Journey through Hungary, Transylvania, and the Banat Mountains*, Freiberg, 1797).

The writings of the energetic but somewhat eccentric traveller Hacquet[1] in many respects supplemented the works of Fichtel.

Hacquet's records of his journeys in the Carpathian and Transylvanian mountains were, however, written towards the close of his active life. His fame is based upon another work, the *Oryctographia Carniolica*, a study of the surface conformation of Carniola, Istria, and neighbouring districts (4 vols., Leipzig, 1778-89). This monograph, which was modelled after the pattern of the Swiss geologists, Scheuchzer and De Saussure, represented the fruit of twenty years' residence in Carniola, and disclosed for the first time something of the mineralogical and physical structure of the more remote southern ranges of the Alps. A geographical map was published along with the work.

The scenic character and physical relations of the country, as well as the customs and character of the population, are excellently depicted. But in the geological portion the author unfortunately confined himself to a barren description of the individual occurrences of rocks, minerals, and fossils, without attempting to give a general conception of the structure. During the years 1781-86, Hacquet extended his knowledge of the Alps by travelling through the Dinaric, Julic, Rhætic, and Noric Alps. He then published a work of a more mineralogical and geological character upon these districts, but he did not succeed in arriving at any real appreciation of the broad features of Alpine structure.

This was a task even beyond the greater powers of Leopold

[1] Balthazar Hacquet (1739-1815) had a varied career. Born in Brittany, he became a surgeon; in that capacity he attached himself to the Austrian Army throughout the Seven Years' War. At the close of the war he taught Surgery at the Lyceum of Laibach, and in 1788 he was made Professor of Natural History and Surgery in the University of Lemberg.

von Buch and Alexander von Humboldt. During the winter spent by the two friends in Salzburg, they made numerous tours into the Salzkammergut and Gosau Valley. Von Buch's account of the geognostic and physical relations in that locality is very pleasant reading; but, biassed as he was by Werner's theories, Von Buch tried to explain the disturbances of the strata by local collapse, and by the shifting of the centre of gravity in the rocks. The beautiful "Königsee" near Berchtesgaden, and the Lake of Hallstadt, were both regarded as local basins of inthrow, and the deep Alpine valleys were attributed to river erosion. The whole massive development of limestone in the higher ranges of the Salzkammergut was taken to be the equivalent in age of the Thuringian "Zechstein" (Upper Dyas). The occurrence of fossils at Hallstadt and Gosau, and other now famous localities, was repeatedly mentioned by Von Buch, but the fossils themselves were not used in any way to help to determine the age of the rocks.

In a separate publication Von Buch drew a comparison between the geological succession observed by himself across the Brenner Pass, and that which had been described by De Saussure for the Mount Cenis Pass. Although the idea was good, the rocks and the stratigraphy in these two distant Passes have too little in common to disclose any broad principles of Alpine structure, and the results obtained by Von Buch in this respect were confused and unsatisfactory.

Some general facts were, however, brought into prominence. In this work Von Buch demonstrated the absence of porphyry at Mount Cenis, as well as in the whole Northern Alps, in strong contrast to the enormous development of this rock south of the Brenner Pass; he compared the northern and southern zones of the Alps with one another geologically; showed the relationship of the Jura mountains, to the Alps and he drew attention to the lithological differences in the rocks, and their influence on the scenic features. In later years Von Buch wrote a few short papers on the Hinterrhein district (1809) and on the Bernina Massive (1814).

One of the most richly endowed of Alpine students was the Zürich geologist, Hans Conrad Escher (1767-1823). In 1796 Escher published a geological survey of the Swiss Alps, and afterwards a series of geological sections from Zürich to the St. Gothard Pass. He also contributed several smaller

papers to Leonhard's *Taschenbuch für Mineralogie* and other journals.

Escher's modest personality is endeared in the minds of all Alpine geologists. His quiet, persistent spirit of inquiry enabled him to amass innumerable observations, which not only afforded a reliable framework for the future, but also contained the kernel of some of the grandest mental conceptions of geological phenomena that have been attained during the progress of Swiss geology.

While Escher's work is so empirical and technical in its tendency as to have retained its freshness for the specialist, his contemporary, J. G. Ebel,[1] has left a work whose chief interest now is for the historian, but which, nevertheless, was a great achievement at the time. Ebel was the first to bring any comprehensive account of Alpine geology to a relatively successful fulfilment. The previous literature of Swiss geology, from which Ebel drew his facts, embraced the works of Scheuchzer and De Saussure, the series of accurate geological sections prepared by the engineer of the Linth Canal, Hans Conrad Escher, and the papers of the younger Escher, which were then appearing in current magazines. De Luc and De Saussure had contributed a few observations on the south-west portion of the Swiss Jura mountains, and Count Razumowsky had published his large work, *Natural History of the Jorat and its Surroundings*, in the second volume of which important suggestions had been given regarding the structure of the Jura mountains. Ebel was also thoroughly familiar with the geological literature of the German, Austrian, French, and Italian Alps; in many cases he relied upon his own observations.

Ebel's description of the Alps was characterised by the

[1] John Gottfried Ebel, born 1764 in Züllichau, Silesia, studied medicine, then travelled three years in Switzerland, and in 1793 settled as a physician at Frankfort-on-Main. A translation of the writings of Sieyès brought him under political suspicion, and he was forced to leave Germany. He went to Paris, where he continued to practise medicine, but spent a large portion of his time in the pursuit of natural philosophy. In 1810 he selected Zürich for a residence, and died there in 1830. During his early years in Frankfort he published a "Guide," *How to Travel in Switzerland in the most Pleasant and Practical Way* (4 parts, 1793), a work which has served as the pattern of our present guide-books for travellers. His next work was *A Description of the Mountain-peoples of Switzerland*, 1798-1802. His chief geological work, *On the Structure of the Earth in the Alpine Mountain-System*, was published at Zürich in 1808.

clearness with which he distinguished the leading members of the mountain-system. He established the fundamental distinction of a central chain composed for the most part of primitive rocks, and two lateral zones on the north and on the south of the central chain, composed chiefly of limestone, sandstone, shale, and nagelflue. These leading zones were accurately described with respect to their geographical distribution and the various kinds of rock present in them. The resemblances and differences between the northern and southern zones were pointed out, and the leading stratigraphical features were shown in a number of geological sections. The text was further illustrated by a general geological map of the Alps and several panoramic sketches. A geological map (on small scale) of the mountain-systems of Europe was added for purposes of comparison.

In describing the Jura mountains, Ebel defined their geographical limits in accordance with their geological structure. He pointed out for the first time that the Swabian and Franconian Alb formed geologically an integral part of the Swiss Jura chain. He also drew special attention to the arched forms of structure as particularly characteristic of the Jura mountains, but failed to find any satisfactory explanation of the curvature of rock-strata.

The main features of the conformation were thus rightly laid down, but the detailed stratigraphy was less ably handled. Ebel started from the assumption that the whole outer crust of the earth is everywhere composed of the primitive rocks, granite, gneiss, and crystalline schist, and that these rocks have been in certain localities covered by pelagic or terrigenous deposits. He regarded the highly-tilted position of the rocks in the central chain as essentially characteristic of the primitive series, and accepted Alexander von Humboldt's doctrine that the primitive rocks everywhere strike in the same direction, from south-west to north-east.

In his treatment of the stratigraphical succession in the lateral Alpine zones Ebel attached little weight to the order of rock-formations enunciated by Werner, and considered it far more important to note the sequence of the fossil contents. He pointed out that the strata reposing upon the primitive group contain a few pelagic fossils; in younger strata the remains of marine faunas are much more numerous and varied; in still younger terrigenous deposits there are fossil fishes and

plants; then amphibians appear, and finally, whole skeletons of terrestrial mammals and birds are imbedded in the sands and clays. "Accordingly fragmentary historical testimony of the beginnings and further stages of living organisms on the face of the earth has been indelibly preserved in the successive strata. It must be left to posterity, by means of the united observations and efforts of many enquirers, to solve the secrets of the earth's structure and read aright the sequence of organic remains interred in the crust" (vol. ii., p. 412).

The periodicity in the recurrence of certain physical conditions and the repetition of similar deposits were favourite themes with Ebel. He showed that the same varieties of rock occur repeatedly in the lateral zones of the Alps, and clearly represent deposits gathered during different geological epochs. Then he cited evidences, both from the central and lateral Alpine zones, of recurrent paroxysms of the crust; these, in his opinion, had been caused by the sudden transgression of the ocean over terrestrial areas and the consequent devastation of the land, erosion of valleys, and accumulation of fine and coarse mechanical deposits at the base of the mountains.

According to Ebel, the last and most violent inundations had advanced in a direction from south-west to north-east, and had transported the huge erratic blocks and the material of the nagelflue and other pebble deposits to the northern band of the Alps, and even as far as the North German plain.

This same idea of periodicity led Ebel further astray when he ventured into philosophical speculations. He compared the body of the earth with a voltaic pile in spherical form, in which a living element analogous with the electrical current not only called forth the plant and animal kingdoms, but also regulated the origin and arrangement of the minerals and rocks.

Such theoretical speculations were always kept apart from the descriptive portion of Ebel's work, and scarcely affected it, although they produced so unfavourable an impression that they caused his work to be undervalued by his contemporaries. At the same time, Ebel's work undoubtedly marks the high level of geological research as it was represented in the Alpine literature at the beginning of the century. Unfortunately, Ebel had no deep insight into stratigraphical details, and he lacked the genius to follow up the indications

which De Saussure and Escher von der Linth had given of the grand crust movements that had inverted rock-strata and developed the fan-structure of the mountain-massives of the central chain. The bolder thoughts of these men escaped him.

In addition to the larger works on Alpine geology by Von Buch and Ebel, a number of smaller treatises on Alpine localities were contributed to mineralogical journals. Amongst these were papers by Italian geologists directing attention to the interesting geological phenomena in the Fassa Valley and Predazzo in South Tyrol; a description by Mohs of the Villach Alps; works by Charpentier and others on the Wallis Alps; and by several French geologists on the Maritime Alps and several parts of the Dauphiné.

C. *Italy.*—The interest of Italian geologists was early attracted to the richly fossiliferous Tertiary strata. Arduino's epoch-making works on the stratigraphical succession in the neighbourhood of Verona have been mentioned above (p. 37). The travelled Alberto Fortis (1741-1803), an Augustine monk, was an acute observer and a prolific writer on geological subjects. His works are for the most part descriptive of the Tertiary deposits and volcanic rocks in the Vicentine Alps; Monte Bolca, a locality long famous for its fossils, was thoroughly searched by Fortis, and he discovered several new localities of well-preserved fossils (Brendola, San Vito, Grancona).

Fortis compared the fossil fishes of Monte Bolca with existing species in the southern seas, and concluded that six or seven species were identical. This opinion was shared by Volta, in whose splendid monograph of the Monte Bolca fishes (1788) the number of fossil forms identical with living species is increased to one hundred and ten. Possibly the best contribution made to science by Fortis was his work on the geological structure of Dalmatia, and his account of the occurrence of nummulites at Bencovac and Sebenico, of bone breccias at Cherso, etc.

In regard to the origin of basalt and tuffs, Fortis was an extreme Volcanist; he even believed that the volcanic energy of the Vicentine area had raised the temperature of the Adriatic Sea to such a degree that tropical molluscs and fishes could then exist in it.

The Tertiary fossils of Italy were made the subject of a masterpiece in palæontological literature, Brocchi's[1] famous monograph, *Conchyliologia fossile subapennina* (Milan, 1814). This work comprises two quarto volumes, and is handsomely illustrated with sixteen plates. It begins with a historical review of the development of palæontology in Italy, depicts in an introductory chapter the structure of the Apennines and the adjoining plains, and distinguishes the Secondary rocks which compose the true mountain-chain from the Tertiary deposits on the lower slopes and plains. The main part of the work is occupied by the specific descriptions of Tertiary mollusca from all parts of Italy. The special locality, the number of specimens, and the particular distribution in sandy or clayey, pelagic, or littoral deposits is accurately recorded for each species; both the descriptions and illustrations are perfect. A special chapter is devoted to the occurrence of land mammals, whales, and fishes.

Brocchi recognises the great similarity of the Tertiary species of mollusca with species still living in the Mediterranean and Adriatic seas, and likewise the difference between the Italian fossil species and the species of the Paris basin, which had been described by Lamarck and Brongniart. He erroneously attributed the dissimilarity of the Italian and French species, not to any difference in the geologic age, but to the separation of the areas of occurrence. At the same time Brocchi fully realised the fundamental difference between the fossil faunas in the Secondary and Tertiary rocks of his native land. The numerous occurrence of Belemnites, Ammonites, Terebratulas, and other generic types in the Secondary rocks, and their complete absence from the Tertiary faunas is explained on the basis of the gradual extinction of the more ancient types during the vast periods of time that elapsed while successive strata accumulated.

Brocchi's ideas about the mode of extinction and period of existence of fossil genera and species are of especial interest.

[1] Giovanni Battista Brocchi (born at Bassano in 1772) studied jurisprudence and theology in Padua, was made Professor of Natural History in Brescia, and afterwards Inspector of Mines for the Kingdom of Italy. He travelled through almost the whole of Italy, and published a large number of mineralogical, geological, and palæontological papers; in 1823 he travelled in the East, visited Lebanon and Egypt, and went as an engineer to the Soudan, where he died in 1826 at Khartoum, a victim to the unhealthy climate.

He opposes the Catastrophal Theory, which taught that from time to time destructive catastrophes had occurred in past ages, and had annihilated the whole or the greater portion of existing forms; and he lays down principles of the evolution of one from another along continuous lines of descent, but in accordance with definite natural laws of growth and decay. He argues that just as a definite span of life is meted out to each individual, and the time may be longer or shorter according to the kind of organisation, in the same way each species and each genus possesses a definite energy of existence, and when that has been exhausted, death ensues from natural causes of decay.

While it is as a palæontologist that Brocchi's name will be remembered, his first contribution was a mineralogical and chemical treatise on the iron-works of Mella, in Val Trompia; he then studied the porphyrites and basalts of the Fassa valley, and, in agreement with Wernerian doctrines, referred them to an aqueous origin. Later in life, after the publication of his monograph, he returned to the study of volcanic rocks, with the result that he became a Volcanist.

The volcanoes of South Italy had always proved an attractive study in scientific circles, and yet it was remarkable how few of the scientific works regarding them had been contributed by those resident in the immediate neighbourhood.

Sir William Hamilton's work on Vesuvius and Etna (p. 45) had prepared an excellent foundation for further research, and a worthy continuation was provided by the Frenchman, Dolomieu,[1] in his descriptions of the Lipari and Pontine Isles, and his detailed mineralogical researches on the rocks of these islands and of Etna.

Dolomieu departed from the usual method of research that

[1] Guy S. Tancrède de Dolomieu, born 1750 at Dolomieu, in the Dauphiné, was an officer in the army; he travelled for several years in Sicily, South and Central Italy, the Pyrenees and Alps; in 1796 he was elected a Professor in the Paris School of Mines, and accompanied the French Expedition to Egypt. While on the return journey he was taken into custody, for political reasons, in Naples, and was imprisoned for two years. After he regained his liberty he became, in 1800, Professor of Mineralogy at the Natural History Museum in Paris, but died in the following year in Paris. His most important works are: *Travels in the Lipari Isles* (Paris, 1783); *On the Earth-Tremors in Calabria* (Rome, 1784); *On the Lepontine Isles, and a Catalogue of the Products of Etna* (Paris, 1788).

had been adopted by his predecessors. Instead of confining himself to a description of the superficial aspect of the volcanic mountains and the characteristic phenomena of eruption, Dolomieu studied the lavas, loose ejecta, sublimations, etc., and compared these volcanic products with other rocks. He thus arrived at the result that all transitional stages exist between the coarsely crystalline lavas and the glassy rocks (obsidian, pitchstone), the latter being merely particular structural varieties of the crystalline lavas.

In order to explain the possibility of so many grades of structure, Dolomieu supposed that volcanic heat, unlike any kind of artificial heat that could be produced in the laboratory, did not reduce the original rock-material to a completely melted mass, but merely to a viscous state, in which the individual mineral constituents could move relatively to one another while still retaining their characteristic form.

He further supposed the lavas contained a combustible substance (perhaps sulphur), which held the rock in this viscous state until it was completely consumed; and that this combustible substance, by its expansive force, produced the scoriaceous, slaggy, and irregular surfaces of lava streams, and caused the upward pressure of molten magma to the orifice of escape.

Dolomieu confirmed the igneous origin of basalt rock, regarding it as a variety of lava for the most part associated with submarine eruptions. He compared the alternating lava streams and sedimentary strata at Etna with the stratigraphical relations of the so-called trap-rocks in the Vicentine district, and concluded that the latter gave evidence of volcanic activity.

The name of Dolomieu is perpetuated in the name of the "Dolomites," given to the beautiful district in South Tyrol south of the Puster Valley. Dolomieu called attention in 1791 to the unusual mineralogical character of the "Alpine limestone" in that district. His chemical investigations proved the rock to contain, in addition to lime carbonate, a very high percentage of magnesium carbonate; so that the rock could by no means be regarded as a true limestone. Afterwards, any highly magnesic limestone came to be called "Dolomite" rock.

In 1797 Dolomieu confirmed the statement of Giraud Soulavie, that the volcanoes of Auvergne and Vivarais are intruded into the granite, and partially rest upon it. Thus Dolomieu extended our knowledge of the mineralogical com-

position of rocks on many definite points, and his researches at once gained recognition. Italian geologists applied themselves with fresh zeal to the study of their volcanic rocks, working more by the practical methods of Dolomieu. Soon they discovered the weaknesses in Dolomieu's writings, where that keen observer had ventured to speculate on the causes which might determine the particular setting and orientation of mineral material characteristic of the transitional varieties of igneous rocks.

The learned Lazzaro Spallanzani (1729-99), Professor of Natural History in Pavia, was the first who applied experimental methods to the elucidation of volcanic rock-structure. He set up series of experiments in his laboratory in order to find out whether gaseous vapour would escape when lava was melted, and what was the chemical nature of such vapours. The result showed that little gas escaped, but the powdered lava partially sublimated, and was partially converted into a vesicular rock-mass.

Spallanzani then tested Dolomieu's idea that the crystalline structure of volcanic rocks was produced under the influence of a moderate degree of volcanic heat acting during a long period. Different kinds of lava were exposed to definite temperatures for forty-five days, some even for ninety days. The result of Spallanzani's experiment appeared negative, since a moderate heat acting for a long time produced precisely the same effects as a more intense heat acting for a shorter period.

Spallanzani also investigated whether, in accordance with the hypothesis of Dolomieu, the presence of sulphur would hasten the fluidity of the lava, and whether the melted material in this case would solidify as a crystalline, rough-grained, or vitreous rock. The result was again negative. The powdered specimens of lava mixed with sulphur demanded the same time to become fluid as the specimens with which no sulphur had been mixed, and on solidifying produced the same glassy rock. Spallanzani therefore opposed Dolomieu's theory, that a combustible substance was present in flowing lava, pointing out (1) that no flames had ever been seen on the surfaces of lava streams; (2) that all lavas were easily brought back to a fluid condition; whereas if Dolomieu were right in supposing they became solid after all the combustible material had been consumed, then in the absence of the latter it should be much more difficult to melt the lavas.

Spallanzani's experimental researches were published in several volumes in the same series as the more popular descriptive account of his travels (*Travels in Sicily and some parts of the Apennines*, 6 vols., Pavia, 1792-97). His descriptions and observations of volcanic regions surpass in scientific accuracy and completeness all previous contributions of the kind, and have secured a permanent place in the literature of scientific travel. Although Spallanzani's numerous experiments invariably produced vitreous rock-varieties, Hall succeeded shortly after in demonstrating that crystalline structure could be produced experimentally by the slow cooling of melted rock.

In 1801, Scipio Breislak (p. 78) published a descriptive and geological work on the Phlegræan fields, the extinct volcanoes near Rocca Monfino, on Monte Somma, Vesuvius, the Baiæ, Procida, and Ischia. This work comprises several maps, and is in many respects supplementary to Spallanzani's *Travels.* Breislak also contributed the first researches on the geology and stratigraphy of Rome, and of that part of the Apennines which surrounds the volcanic area of the Italian mainland.

Leopold von Buch was also a contributor to the geology of Rome. His study of the basalt of Capo di Bove and the Alban mountains aroused in his mind the first doubts of the correctness of Werner's Neptunian doctrine. The best feature in Von Buch's summary of the geology of Rome is his lucid exposition of the travertine and tuff deposits. He demonstrates that these are true aqueous sediments, although he recognises the volcanic origin of many of the contained mineral fragments.

In a paper "On the Formation of Leucite," Von Buch tried to prove that the crystals of leucite in the lava had separated out while the material was still in a fluid state. In his estimation the leucite crystals were original volcanic products; he discredited the hypothesis that they had been originally components of an aqueous sediment which had been partially melted in subterranean volcanic cisterns and poured forth as lavas. The anti-Neptunian attitude assumed by Von Buch in this paper was turned to good account at the time by the Volcanists. But Von Buch still held a somewhat contradictory position regarding basalt.

After he had visited Vesuvius and the Euganean Isles, in 1799, he wrote to Pictet that little difference could be distinguished between the lava flow from Torre del Greco

and basalt rock; but as Hall's experiments had shown that basalt when melted could again solidify in crystalline form, he supposed that the lavas of Vesuvius represented a pre-existing basalt of aqueous origin which had been melted in the earth's crust and ejected as lava. In other cases, for example at Solfatara, the lava might not be basaltic in character, and might have some other origin. In the same letter he gave a description of the definite sequence in the eruptive phenomena of Vesuvius. The eruptions, he said, begin with earthquakes, radial fissures form on the slopes of the mountains, and lava wells out; then the pent-up steam and vapours burst forth from the central vent with explosive force and noise, throwing into the air enormous masses of ashes and fragmentary scoriæ amidst dust and smoke. After the crater is emptied, quiet is regained, the exhalations of injurious gases marking the final stages of a spent volcanic outburst.

While our scientific knowledge of volcanoes was derived in great measure from Italy, that country also was the scene of the series of earthquake shocks which convulsed Calabria in 1783. Great importance is attributed to the Calabrian earthquake in scientific literature, from the circumstance that many of the observers present in Calabria during the disturbance, or immediately after it, were experienced men of science, and their vivid descriptions and accurate observations and drawings afforded the first circumstantial scientific account of earthquake phenomena.

D. *France, Belgium, Holland, and the Iberian Peninsula.*—During the eighteenth century France had fallen behind Great Britain, Germany, and Italy in the pursuit of geology and palæontology, but the influence of Buffon revived a warmer interest in these studies. Scarcely any other country in Europe offers such a fine field for geological studies as France. Apart from the Pyrenees, Alps, Brittany, and the Ardennes, the stratigraphy of French districts is comparatively simple, and the strata abound with a wealth of well-preserved fossil remains. In addition, there is the wonderful Auvergne district, with its groups of extinct volcanoes, discovered by Guettard in 1752.

Desmarest was the French geologist whose genius disclosed the full significance of these extinct volcanoes and made Auvergne famous. In 1763 he observed on the plateau of

Prudelle, near Clermont, basaltic pillars in close relationship with a lava flow, and he spent many years in collecting facts to prove the volcanic origin of the basalt. The work which he published in the *Mémoires de l'Académie royale des Sciences* (1774-75) established the igneous origin of basalt without a shadow of doubt.

Desmarest was himself so entirely convinced of the result of his conclusions that he took no part in the strife between Neptunists and Volcanists, but when questioned by any hesitating adherents of either party he used to reply laconically, "Go and see."

It was remarkable how completely Werner and his school ignored the incontestable results of Desmarest. And the later work by Desmarest, "On the Determination of different Epochs of Volcanic Activity in Auvergne," was also neglected in Germany (*Mém. de l'Inst. Sc., Math. et Phys.*, 1806). His own countrymen, however, fully realised the value of Desmarest's achievements. Following the same lines as Desmarest, Faujas de Saint-Fond and Abbé Soulavie made known the volcanoes of Vivarais and Velay with their magnificent basaltic pillars and lava streams; so that when D'Aubisson, a student of Werner's, returning to Paris from Freiberg, tried to spread Neptunian doctrines, he had no success, and a visit to Auvergne converted D'Aubisson himself to Volcanistic beliefs.

The intellectual politician and scientific investigator, Count Reynaud de Montlosier, published in 1789 an *Essay on the Volcanoes of Auvergne*, in which he promulgated a new theory about volcanoes. Like Desmarest, Montlosier recognised that there were in Auvergne volcanoes of different ages. The younger have preserved their typical conical form and their craters uninjured. The older are for the most part situated at higher levels, and these characteristic features are absent; they are connected ridges or isolated mountains composed of pillared basalt, or trachytic rocks, frequently reposing on granite. Whereas it is clear that the younger craters and cones of loose ejected material and lava are of true volcanic character, Montlosier claimed for the older and relatively higher groups of igneous rocks that they represented a single upheaval of an extensive viscous mass of rock-material that had then cooled in the elevated position.

The Pyrenees also attracted the attention of French geologists towards the close of the eighteenth century. Abbé

Palassou wrote the first full scientific description of the geological structure of the Pyrenees. He worked nearly forty years in this district, and in 1782 published his *Essay on the Mineralogy of the Pyrenees Mountains.* The work comprises eight mineralogical maps on a large scale, and twelve plates with panoramic views. After the precedent of Guettard, Palassou used special symbols to distinguish the different rocks and minerals on the maps; and took careful observations of the strike and dip. Palassou concluded that the whole mountain-chain is made up of limestone, shales, clay, and granite, with a general strike in W.N.W. and E.S.E. direction, and he gave a number of transverse sections displaying a simple and uniform structure throughout the chain.

Palassou's work was based upon principles which were already somewhat antiquated when the work appeared. He believed that the sedimentary rocks had been deposited in the various inclined and horizontal positions in which he found them. Limestones and fossiliferous shapes of all ages were termed Secondary formations; no attempt was made by Palassou to determine systematic sub-divisions according to the rock varieties, the fossils, or any other individual feature, and he discarded the "transitional" series of formations between the primitive granitic rocks and the Secondary formation.

Among the varieties of rock a diabasic rock containing uralite was described for the first time under the name of *Ophite.*

An engineer, Picot de Lapeirouse, published a finely illustrated work on the Rudistes or Hippuritidæ, a fossil Lamellibranch family represented in great numbers of individuals in the Cretaceous deposits of the Pyrenees. This remarkable genus had been discovered by Abbé Sauvage in the Cevennes mountains forty years previously. Unfortunately Lapeirouse, beautiful as his illustrations are, entirely misjudged the place of these fossils in the animal world, and called his work *A Description of several new kinds of Orthoceratites Ostracites* (Erlangen, 1781).

Ramond de Carbonnières contributed several geological and palæontological works on the Pyrenees. He was an enthusiastic mountaineer and made a special examination of Mont Perdu, which was then thought to be the highest summit of the chain. He proved that this summit was not composed of

granite as had been supposed, but of "Secondary" limestone containing numerous marine fossils. Ramond also drew attention to the presence of horizontal and inclined strata, and to the fan-shaped form in which the inclined strata were often arranged.

Johann von Charpentier (1786-1855), the son of Wilhelm von Charpentier (p. 38), travelled as a young man for four seasons in the Pyrenees (1808-12). The geological work which he published in 1823 was for a long time the standard work upon these mountains. The younger Charpentier agreed with Palassou and Ramond regarding the parallel trend of the strata along a definite strike, and demonstrated that the sedimentary strata slope away from the granite core of the chain. He established for the first time that there was a transverse fault through the whole breadth of the chain between Montrejeau and Perpignan, the eastern part of the chain having been displaced to the north relatively to the western portion.

As a student and follower of Werner, Charpentier, like Palassou, supposed that the aqueous deposits had consolidated in their inclined position, and gave no credence to ideas of subsequent uplift and disturbance. He distinguished eight formations, in ascending order—granite, mica schist, primitive limestone, transitional limestone, red sandstone, Alpine limestone, and Jura limestone, ophite and terrigenous deposits (Tertiary and Diluvium). Charpentier gave little attention to the fossils, therefore not infrequently made blunders with respect to the age of the stratigraphical deposits. For example, Charpentier's "primitive" limestone corresponds to Silurian and Devonian formations; his "transitional" limestone, containing belemnites and ammonites, corresponds to the Jurassic formation; his "Alpine" limestone to Cretaceous and Lower Tertiary rocks. In spite of these shortcomings, Charpentier's work was one of the most important of his time.

Occasional observations had been made on the "Paris Basin of Deposits" by Guettard, Desmarest, and others; Lamanon gave special attention to the beds of gypsum near Paris, and rightly regarded them as the deposits of a freshwater lake. De la Métherie had attributed them to volcanic origin. Lamanon, however, found fossil specimens of a freshwater mollusc in the interstratified marls, and in the gypsum bones of terrestrial mammals different from those of living

species. The great chemist Lavoisier made several geological sections through the Paris basin, and pointed out the alternation of littoral and pelagic deposits. The stratigraphical succession established by Lavoisier was added to by Coupé's detailed examination of exposures in the vicinity of Paris.

The greatest work on the "Paris Basin" appeared in 1808, in the *Journal des Mines* and *Annales du Muséum*. The authors were Brongniart, Professor of Mineralogy in the Natural History Museum in Paris, and Cuvier, the famous zoologist and palæontologist. They drew up a systematic table of the succession of stratigraphical horizons in accordance primarily with the sequence of the deposits in the ground, and with the particular fossils characterising each group of deposits; the varieties of rock, and the thicknesses and distribution of different deposits were also fully considered. The following are the formations, in ascending order from the Cretaceous rocks, as they were recognised in the first work by Brongniart and Cuvier:—

9. Loess clay and pebble deposits, containing bones of large terrestrial mammals.

Now rank as Oligocene deposits.

8. Unfossiliferous millstone quartz and fresh-water limestone of Beauce (Orleans), containing species of Planorbis, Cyclostoma, Helix, and terrestrial plant-remains.
7. Sandstone, without molluscan remains (Fontainebleau sandstone).
6. Siliceous limestone, a facies of deposits 5 and 7 present in the southern parts of the basin.
5. Sands and sandstone with molluscan remains (Fontainebleau sandstone).
4. Gypsum and fresh-water marls, etc., with Planorbis, Linnæus, etc., passing upward into marine oyster beds.

Now rank as Eocene deposits.

3. Sands and coarse limestone series of Paris.
2. Plastic clay without fossils.

1. Cretaceous rocks; fifty fossil species were enumerated in the chalk deposits.

A second and larger work was issued by the same authors in 1811, with a special part devoted to geological descriptions,

maps, and sections. The stratigraphical succession was slightly changed; eleven sub-divisions were recognised instead of nine, the millstone quartz in No. 8, and the marine oyster beds in No. 4, being erected into independent sub-divisions.

Upon the basis of their measurements of the thickness of individual deposits, Brongniart and Cuvier were able to arrive at definite conclusions regarding the configuration of the chalk surface before the deposition of the plastic clay. They demonstrated that the clay had been deposited upon an irregular surface of pre-Tertiary hills and valleys, and that, owing to the inequalities of the base of deposit, neither the clay nor the succeeding coarse limestone series extended over the whole area as connected layers. After the deposition of the coarse limestone, the sea withdrew, and the Paris area then became a fresh-water basin in which calcareous, gypsiferous, argillaceous and marly sediments successively accumulated. The gypsiferous strata were thickest in the middle of the basin, but neither they nor the fresh-water sediments were smooth layers. It was only when the sea once more had ingress and brought into the basin immense quantities of sand that an even surface of deposit was attained. Again the sea retreated, and the area became one of marshes and lakes in which the younger calcareous and siliceous deposits gathered; as the area continued to emerge the surface was eroded, and valley depressions and uplands took shape which were quite independent of the pre-Tertiary configuration.

The importance of this work for geology will be realised when it is remembered that with the exception of formations 1 and 9, all other formations in Brongniart and Cuvier's Table were unknown in Werner's system of the rock-succession (p. 58). Afterwards it was demonstrated that many of the fossils of the Paris basin agreed with the fossils in the deposits near Verona which Arduino had termed *Tertiary deposits*. And the series was then incorporated in the chronological succession of the rocks as the Tertiary formations.

This was also the first French work which adopted the method introduced by William Smith in England ten years previously, of determining the respective ages of the rocks by means of the fossils contained in them. And in this sense the work had a revolutionary effect on French geology.

In a later publication Brongniart extended his observations to the fresh-water deposits of other neighbourhoods—Orleans,

Le Mans, Aurillac, and Limagne. Brard covered a wider field of research, and added still further to the investigation of the fresh-water deposits and their fossils (*Annales du Muséum*, 1809, 1810).

The zoologist, De Férussac, made a special research of the molluscan species in the fresh-water limestone near Mainz, in Quercy, and in Spain. His publications in the Memoirs of the Institute (1812 and 1813) proved that of about eighty-five species nearly all had become extinct; a few, however, could be identified with species still living in distant neighbourhoods or indigenous to Central Europe. Férussac confirmed Brongniart in his opinion that the molluscan species could be used to determine the age of fresh-water deposits.

So much interest had been aroused in these Oligocene deposits that Omalius d'Halloy,[1] the Belgian geologist, made an examination of the series in Auvergne, Velay, and in parts of Italy and Germany, and in all cases proved conclusively that the fossil remains had been imbedded in the deposits of fresh-water marshes, and were not remains which had been accidentally swept into marine deposits.

The Belgian geologist supplemented the observations of Cuvier and Brongniart with great success. With unceasing diligence, he conducted geological tours on foot during ten years, and as a result he was enabled to produce a geological map of France and the adjoining territories of Belgium, Germany, and Switzerland. The map gave a faithful representation of the distribution of the leading geological formations. It was first published in 1822, on the scale of 1 : 4,000,000, and was in later years improved and incorporated in D'Halloy's *Text-book of Geology*.

Early in his career, D'Halloy had regarded the position of the strata, their horizontal, slightly or highly inclined, or vertical position, of great importance in determining the age of the strata. He thought the horizontal strata corresponded to Werner's "Flötz formations," and all inclined strata to

[1] Jean Baptiste Julien d'Omalius d'Halloy, born 1783 in Liége, the only son of a rich aristocratic family, came under the influence of Brongniart, Cuvier, Faujas, and Lamarck in Paris; he devoted himself from 1804 to 1814 wholly to the pursuit of geological researches in France, Belgium, and the neighbouring districts; in 1815 was appointed Governor of the Province of Namur; afterwards a Member of the Belgian Senate, and President of the Academy of Sciences in Brussels; died 1875.

Werner's "Transitional formations." But his subsequent visit to the Alps and Jura mountains caused him to modify these views.

He accomplished new and important work of investigation in the Carboniferous districts of Belgium and the Rhine Provinces. He showed the extensive development of the highly-tilted slate formation in the Ardennes, the Eifel and Hunsrück, and pointed out that in the Rhine Province and in the Palatinate (Pfalz) this formation had been penetrated by volcanic rocks. The productive horizons were chiefly developed in the northern French provinces, Artois and Boulonnais, while the fossiliferous strata beneath the coal-bearing series were best developed in the Hennegau. Thus Omalius d'Halloy laid the foundation of geological knowledge over wide areas. His more detailed works are those which deal with the Tertiary deposits of the Paris basin. He united horizons 5 and 7 in the classification system of Brongniart and Cuvier, and traced the topographical distribution of each horizon.

The hill of Petersberg, near Maestricht, was made the subject of a local monograph of high excellence by Faujas de Saint-Fond. The chalk series of this district has since been recognised as the uppermost horizon ("Danian Stage") of the Cretaceous formation, a stage absent in the British development, but of very great interest from the intermediate Cretaceous-Eocene character of the fauna.

The monograph of Faujas de Saint-Fond begins with a description of the hill and the deposits, more especially the system of caverns and tunnels that had been excavated in the rock. In the palæontological portion, the first specimen described is the huge reptilian skull, *Mosasaurus Camperi*, that had been found in these deposits in 1770. The specimen originally belonged to a physician of the name of Hoffmann, but, as the result of a lawsuit, it came into the custody of the Canon Godin, and finally, after the siege of Maestricht by the French in 1795, it was demanded as booty of war and transferred to the Paris Museum. The famous anatomist, Peter Camper, had examined the jaw of a similar fossil animal and identified it as the remains of a Cetacean, nearly allied to the genus Physeter, whereas Faujas tried to demonstrate that it represented a fossil crocodile. Both indications were proved erroneous by Cuvier, who identified the remains as those of a marine serpent-like reptile, and placed the genus Mosasaurus among the lizards, in near relationship to the genus Varanus.

Other remains from the Maestricht chalk that had been erroneously classified by Faujas and his predecessors were some large marine chelonians, which Cuvier again was the first to identify correctly.

Faujas' descriptions and illustrations of Invertebrate groups were particularly good. Only the want of an adequate scientific terminology, distinguishing the original specimens according to genus and species, has prevented the monograph from taking a permanent place in the works of posterity, as it must otherwise have done. Faujas himself seems to have had no further aim in view than to show how important the accurate description of the fossils of one limited locality might be for palæontology and geology, inasmuch as these descriptions could be used as a definite basis of comparison with the fossil remains in other localities.

There is little to relate about the geology of the Iberian Peninsula at this period. After the brilliant successes achieved by the Spanish and Portuguese mariners in the fifteenth and sixteenth centuries the sciences became neglected, more especially the natural sciences. The first work devoted to Spanish fossils in the Spanish language was written by a Franciscan father, Jose Torrubia (*The Natural History of Spain*, 1754). The author had travelled in America and the Philippines, and had collected fossils and minerals from various lands. He drew up a complete list of all localities where fossils had been found, and gave illustrations of the Spanish fossils on fourteen large plates. Minor works were published on local physical and geographical relations by Bowles, an Englishman resident in Spain, and by the Spanish botanist, Cavanilles, on the occurrence of fossils in the province of Valencia.

E. *Great Britain.*—Researches into the constitution and history of the earth were always held in high regard in Great Britain. The natural wealth of the country in coals and useful minerals, the early development of mining and smelting, the frequent discovery of well-preserved fossils, had all contributed to awaken widespread interest in a knowledge of rocks. Many who had less sympathy for the scientific aspect of the subject found themselves attracted by the literature that was called forth in the effort to bring each new geological fact as it came to light into harmony with the tenets of Biblical inspiration.

Thus, in addition to strictly empirical writings, there grew up an independent speculative literature in which the names of Whiston, Burnet, and Woodward are prominent.

Towards the end of the eighteenth century, in 1789, John Williams, director of mines, published a *Natural History of the Mineral Kingdom*, with a description of the coal-beds and their occurrence in Great Britain, which was remarkably complete. Williams was a violent opponent of Hutton, whom he blamed for disbelief in the Deity.

The hazy suggestions of Robert Hooke and others, that fossils might perhaps be of use in identifying the chronological order of the rocks, had remained unheeded for more than a century. The greatest stratigraphers on the Continent, Lehmann, Füchsel, Arduino, had directed their attention far more to the constitution of the rocks than to any benefit that might be derived from a study of fossils. Giraud Soulavie and Buffon had conceived some idea of the floras, but had not ascertained any sure method of applying such variations to problems of historical geology and stratigraphy.

William Smith,[1] an English engineer, was the first to recognise the importance of fossils in their full significance as a means of determining the relative age of strata. Born in a county that was unusually rich in fossil remains, he had in his boyhood abundant opportunity of observing and collecting. As assistant to a land-surveyor he became intimately acquainted with the counties of Oxfordshire and Hampshire, and with the surroundings of Salisbury and Bath.

[1] William Smith, born on the 23rd March 1769, at Churchill in Oxfordshire, son of a farmer, received a scanty elementary education at the village school; managed, however, to train himself to some extent in geometrical studies, and entered at the age of eighteen as an assistant in a land-surveyor's office. He was afterwards employed as engineer in the construction of a canal in Somersetshire, and practised independently as land-surveyor and civil engineer. He lived in London from 1801 to 1819; in 1828 he became factor for the estates of Sir John Johnstone. After the Geological Society was founded, William Smith was in 1831 the first recipient of the Wollaston medal; in 1835 the University of Dublin made him an honorary Doctor of Laws; and in 1838 he was a member of the commission for the building material of the Houses of Parliament. During the later years of his life he was in poor circumstances; a small pension was granted to him by the Government, and he died unmarried at Northampton in 1839. (Biography of William Smith in Sedgwick's Presidential Address, *Proc. Geol. Soc. London*, 1831, p. 279; John Phillips, *Memoirs of William Smith*, 1844.)

In 1791 he observed the agreement of the red marl and the Lias near Bath with the corresponding strata in Gloucestershire, and also their unconformable position upon the Carboniferous formation. For twenty-five years William Smith continued his investigations in all parts of England; he entered his observations in coloured geological maps, and compiled them from time to time in the form of tables or as explanatory notes to his maps. He also carried out a scheme of arranging a collection of fossils according to the succession of strata; his own collection was acquired by the British Museum, and is still exhibited there. After his long period of field observations, William Smith came to the conclusion that one and the same succession of strata stretched through England from the south coast to the east, that each individual horizon could be recognised by its particular fossils, that certain forms reappear in the same beds in the different localities, and that each fossil species belongs to a definite horizon of rock.

Like his famous contemporary Werner, William Smith also had a disinclination for writing; on the other hand, he was always willing to communicate the results of his investigations orally. It is told of him how in the year 1799 he made the acquaintance of the Rev. B. Richardson, in Farley, who owned a large collection of fossils from the neighbourhood of Bath. To Richardson's astonishment, Smith knew better than the owner himself where the individual species had been found and in which particular horizon of rock.

Then a dinner was arranged, at which William Smith met another enthusiastic fossil collector, Rev. W. Townsend, and William Smith consented to dictate a table of the British strata from the Carboniferous to the Cretaceous formation. The table of strata was rapidly copied and distributed among geologists. The original manuscript, written by Richardson and dictated by Smith, is in the possession of the Geological Society in London. In this first table of Smith's the successive strata were indicated by numbers.

But Smith was not content with the determination of a chronological succession of strata; he traced their surface outcrops, and thus built up the material for his maps and sections. He laid before the Board of Agriculture a series of memoranda and geological maps which were published between 1794 and 1821 in the form of

excellently printed detail-maps of fifteen counties. These maps were on such a large scale, and so full of details, that they had a limited circulation. Smith therefore conceived a plan to publish a geological map of England and Wales on a small scale, that should show accurately the course of the surface outcrop of each stratigraphical horizon, and should be accompanied by geological sections to the true scale of the map. The preliminary sketch of this plan was drawn up in 1801, and may be seen in the Archives of the Geological Society; but it was 1812 before Smith found a publisher to undertake the map. In 1815, the famous map of England and Wales appeared, consisting of fifteen sheets in the scale of 1 inch to 5 miles. The complete map is 8 ft. 9 in. high and 6 ft. 2 in. broad. The individual strata are indicated by different colours, and sometimes the basis of a stratum is marked by a darker line of the ground colour.

Smith's map is the first attempt to represent on a large scale the geological relations of any extensive tract of ground in Europe. It was a magnificent achievement, and was the model of all subsequent geological maps. For English geology, the publication of the map was the starting-point of a new *régime*. Smith gave an explanatory text of fifty pages, in which he introduced a stratigraphical terminology adopted from the local names in practical use (Lias, Forest-Marble, Cornbrash, Coralrag, Portland Rock, London Clay, etc.), and these names of horizons have for the most part been retained in geology to the present day.

Between 1816 and 1819, Smith began a work entitled *Strata identified by Organised Fossils, containing prints of the most characteristic specimens in each stratum.* Four volumes appeared containing the description of sixteen strata and their characteristic fossils, from the horizon of Fuller's Earth to London Clay, but the work was never completed. In 1817 he prepared an ideal geological section across England from London to Snowdon, and the section was afterwards introduced into most text-books. A contemporaneous account of Smith's results and his terminology was published in 1818 in a small book written by William Phillips.

William Smith was a self-taught genius of rare originality and with exceptionally keen powers of observation. Without much intellectual cultivation, without any introductory teaching, without any means at his disposal, and at first even

without the encouragement and sympathy of colleagues in the study which he loved, his own unflinching determination, noble enthusiasm, and remarkable insight enabled him to elucidate the structure of his native land with such clearness and accuracy that no important alteration has had to be made in his work. Smith confined himself to the empirical investigation of his country, and was never tempted into general speculations about the history of formation of the earth. His greatness is based upon this wise restraint and the steady adherence to his definite purpose; to these qualities, the modest, self-sacrificing, and open-hearted student of nature owes his well-deserved reputation as the "Father of English Geology."

Soon after their publication, Smith's researches were productive of results which he could never have anticipated. It was found that the strata described by him from the Lias to the Purbeck horizons filled the great gap between the Muschelkalk and the Cretaceous formations in Werner's system. European geology was thus enriched by the accurate knowledge of an important series of fossiliferous geological horizons, and the equivalents of the English Lias, Cornbrash, Portland and Purbeck series were sought for and discovered in various parts of Europe.

George Greenough,[1] the founder of the Geological Society of London, published a geological map of England and Wales in 1819, soon after the appearance of W. Smith's. The topographical groundwork and technical workmanship of

[1] George Bellas Greenough, born 1778, at first studied law at Cambridge and Göttingen, but under Blumenbach's guidance turned to natural science, and afterwards studied mineralogy and geognosy with Werner in Freiberg; travelled in Germany and Italy; became a Member of Parliament in 1807, and in the same year, on November 13th, founded the Geological Society of London; died 1855 in Naples. The Geological Society has exercised a strong and favourable influence upon the development of geology in England. The aim in founding the Society was to unite all the English geologists, and to keep alive and encourage the interest in geology by the regular publication of memoirs, *Transactions*, and shorter reports of the communications made at the meetings. The first of six volumes of *Transactions* appeared in 1811. Much later, in 1845, the *Transactions*, published in quarto form, were replaced by the *Quarterly Journal*, fifty-two volumes of which have now been published, and have upheld the high quality of the Society's publications. Mr. Greenough, the first President of the Society, helped very considerably to supply the means for endowment of the Geological Society.

A. G. WERNER.

Greenough's map were particularly good; the geological colouring embraced Smith's results, and was partially founded upon his own observations. The original edition appeared in six sheets; in 1826 a reduced map was published and at once obtained a wide circulation. New and improved editions of Greenough's map continue to appear at the present day, and for a long time this map was the best that existed.

Smith's example gave a new impulse to geological work. John MacCulloch,[1] a physician in private practice, gave up his practice and devoted himself between 1811 and 1821 to the geological investigation of Scotland. The first fruits of his important labours were published in 1819 in his *Description of the W. I. of Scotland.* In 1826 he was commissioned by the Minister of Finance to prepare a geological map of that country. This large undertaking was completed in 1834. There were, however, no detailed topographical maps of Scotland available at that time, and MacCulloch had to enter the geological colours on the meagre topographical basis of the Arrowsmith map. MacCulloch's map was published posthumously in 1840. It frequently passed under the name of the author of the topographical map, and received on its appearance little attention even from geologists. Nevertheless, MacCulloch was one of the pioneers of British mineralogy and geology.

The country which he investigated was bristling with complexities and difficulty of every kind, but a wide mineralogical knowledge and experience stood him in good stead, and he built up a thorough groundwork for the general features in the distribution of the rock-varieties in Scotland. Although a little unwillingly at first, owing to MacCulloch's personal peculiarities and unpopularity, his memoirs have long been recognised as classical works in the history of British geology. They are characterised by accurate mineralogical determination

[1] John MacCulloch, born 1773 in the island of Guernsey, of Scotch descent, was educated in Cornwall, and studied medicine in Edinburgh. He became so enamoured of mineralogical studies that in 1811 he gave up his practice, and in the same year he communicated to the Geological Society several papers on the structure of the Channel Isles and Heligoland. In 1814 he was appointed a geologist on the Trigonometrical Survey. He belonged to no particular school; he frequently fell into scientific disputes with his contemporaries, and was very unpopular on account of his peremptory way and jealous temperament. He died in 1835, through a carriage accident in Cornwall.

of the rocks, and by their extraordinary number of careful observations.

Farey published a *General View of the Agriculture and Minerals of Derbyshire* in 1815, with geological sections and maps. Thomas Webster and Professor William Buckland[1] studied the character and distribution of the younger sedimentary rocks of England. Buckland described in detail the pebble and sand deposits above the Tertiary formations and below the very youngest fluviatile, lacustrine, or marine deposits. He identified the widely-distributed pebble-beds with the epoch of the universal Deluge, and called them *Diluvial detritus;* the youngest deposits he termed *Post-diluvial* (alluvial) *detritus.* He also made a large collection of fossils from the Liassic and Oolite series in the Midlands, and followed William Smith's initiative in working out successive horizons upon palæontological evidence. Buckland's system of the Secondary formations, more especially of the Jurassic formation, has remained a model of clearly-defined palæontological horizons of strata.

The magnificently-formed basaltic pillars of Staffa, the Giant's Causeway, and County Antrim early attracted notice. Pennant's *Book of Travel* (1774) gave descriptions and illustrations of these, without attempting any explanation of their origin. John Whitehurst (1786), the Rev. William Hamilton (1790), and Abraham Mills (1790) advanced the idea of a volcanic origin, and Faujas de Saint-Fond, after a journey in Scotland and Ireland, supported this explanation.

On the other hand, Kirwan (1799) and the Rev. William Richardson (1808) reported the discovery of fossils in the basalt of Ballycalla, near Portrush, and consequently advocated the aqueous origin of basalt, trap, granite, etc.; but Playfair proved that the supposed fossiliferous basalt of Portrush was only metamorphosed Lias.

Contributions to the geology of Ireland were made by Conybeare and Buckland (1813), Vaughan Sampson (1814),

[1] William Buckland was born 1784, the eldest son of the Rev. Charles Buckland, at Axminster, in Devonshire; studied theology in Oxford, and was a Fellow of Christ's College there. In 1813 he was appointed Professor of Mineralogy, and in 1819 was made in addition the first Professor of Geology in Oxford; in 1845 he became Dean of Westminster. He died 1856, held in the highest respect and esteem by all English geologists. (*The Life and Correspondence of William Buckland*, by his daughter, Mrs. Gordon; London, 1894.)

and Dr. J. T. Berger, of German birth, who had been trained in Werner's school. Berger's description of the geology of N.E. Ireland, published in 1816, with a preface by Conybeare, has proved fundamental in the geological literature of that country, while the geological maps of Ireland, published by Richard Griffith in 1834 and 1838, afforded a complete general survey of the stratigraphy.

In Scotland, Robert Jameson (1774-1854), an enthusiastic pupil of Werner, tried to establish Neptunian doctrines. He founded a Wernerian Natural History Society in Edinburgh, wrote a *Text-book of Geognosy* upon Werner's principles, and was for fifty years Professor of Geology in Edinburgh University. He and his students made many valuable researches in Scottish mineralogy, petrography, and geognosy, but their biassed Wernerian view of the rock-formations prevented them from attaining any real insight into the complex stratigraphical relations of the sedimentary deposits in Scotland.

Hutton strongly opposed the Neptunian teaching of Jameson, which was contrary to all his experience in Scotland. On one occasion in 1783, when Hutton was on a visit to the Duke of Athole, he happened to observe red granite dykes near Glen Tilt, in the Grampians, penetrating black mica schist and limestone. He was so overjoyed at the sight that his companions could not understand what was the matter, and thought Hutton must have discovered a gold-mine in the rocks! Afterwards at Cat's Neck, Hutton saw dykes of trap-rock intruded in all possible directions through sandstone. These observations formed the basis of his paper "On Granite," wherein he proves that granite is frequently younger than sedimentary aqueous deposits. John MacCulloch brought subsequent confirmation of Hutton's views by showing that intrusive dykes of basalt, porphyry, granite, and other varieties of igneous rock, abound in the Western Isles of Scotland, and that the stratified deposits have been altered at zones of contact.

F. *Scandinavia and Russia.*—The first Scandinavian scholar who interested himself in the history of the earth was Urban Hiärne (1641-1724). His work, published in 1694, draws its conceptions of the earth's interior chiefly from Athanasius Kircher. While he recognised fossils as the remains of organisms, he

supposed these organisms had come into existence after the Deluge. To the epoch of the Deluge he also attributed gigantic disturbances of the earth's surface that had uplifted great portions of Scandinavia and thrown other areas into the interior of the earth. He thought that frequent recurrences of disturbance had taken place, elevating and destroying mountain-systems and continents.

Hiärne's work was written in his own language, and was little read outside Sweden. The scientific writings of Emanuel Swedenborg, the religious enthusiast, were more widely read. Swedenborg (1688-1772), who held for a long time the post of Assessor of Mines in Sweden, took a great interest in fossils, and in his *Observations of Natural Things* (1722) he mentions and describes a large number of Swedish fossils. He thought the fossils found in high tablelands and mountains had been left there by the flood; he regarded the trap-rocks (Swed. *trappa*, a stair, from the characteristic weathering) as aqueous sediments, and referred volcanic phenomena to the presence of molten reservoirs within the solid crust of the earth.

A work devoted to palæontological details was published in 1727 by Magnas von Bromell; his *Lithographia Suecana* treats of trilobites, corals, and gastropods from Gothland, and of graptolites and plant-remains in calcareous tuff. Another author, Kilian Stobæus, described the first known Ammonites and the so-called "Brattenburg pennies" from the Cretaceous deposits of Schonen. The year 1743 was signalised by the publication of the famous observations made by Anders Celsius on the sinking of the sea-level in the Gulf of Bothnia. Celsius reckoned the lowering of the sea-level at 450 ft. in 10,000 years.

Carl von Linné (1707-78) published in 1756 his account of a geological tour that he made as early as 1741 with six students to Oeland and Gothland. At West Gothland Linnæus had investigated very carefully the horizontal strata of the "transitional formations" (now identified as Silurian and Cambrian), succeeded by a series of trap-rocks well exposed at the Kinnekulle hill. A typical section through the Kinnekulle hill was drawn up by Johan Svensson Lidholm, under the guidance of Linnæus, and it was taken as a standard for the stratigraphical relations throughout Sweden. Linnæus assigned the trap or igneous series to aqueous origin. In

1749 he examined the Cretaceous rocks in Schonen, and in the last edition (1768) of his *Systema Naturæ* he gave a complete list of the fossils known to him, and arranged them according to their occurrence in his system of the rock succession. He arrived also at remarkably clear conceptions about the accumulation of different kinds of sedimentary deposit upon the floor of the ocean.

While Linnæus was a true empirical observer, and may be regarded as the founder of constructive geology in Sweden, a contemporary of his, Tobern Bergman (1735-84), inculcated theories regarding mineral structure and the constitution of the earth's crust which were largely adopted by Werner, and were thus destined to wield a European influence. His *Physical Description of the Globe* (1769) was translated into German, and was the foundation of the Wernerian doctrine that the earth's crust was composed of successive strata of different thicknesses and constitution, but uniformly enveloping the spherical earth; further, that these have arisen as chemical precipitates, and not simultaneously, but gradually during protracted epochs of time. In addition there were deposits accumulated by mechanical means and volcanic rocks. He classified the rock-succession in four sub-divisions: (1) *Primitive* rocks, comprising the chemical precipitates; (2) the *Flötz* series, comprising sediments of mechanical origin; (3) *transported* rocks; (4) *volcanic* rocks.

Daniel Tilas (1712-72) made a special study of the erratic blocks and superficial pebble-beds of Sweden. He wrote strongly on the importance of petrography, and to his warm advocacy Sweden doubtless owes the preparation of its earliest geological maps: the map of West Gothland by Hisinger in 1797, and the maps of Nerike, Schonen, West and East Gothland by Gustaf Hermelin, published between 1797 and 1807. Both these authors contributed an explanatory text to their maps, and thus laid the basis of stratigraphy in Sweden. Hisinger (1766-1825) wrote a general description of the mineralogical relations of Sweden; and the second edition, soon after its appearance in 1808, was twice translated into German. This work contains a historical review of all the facts known about Swedish rocks up to that date, and applies Werner's systematic arrangement.

The oldest information about the geography, minerals, and rocks of Norway is to be found in Erich Pontoppidan's *Natural*

History of Norway, 1753. In the beginning of the nineteenth century, Werner's scholar, Jens Esmarch, conducted mineralogical investigations in Norway. J. L. Hausmann travelled through Scandinavia in 1806 and 1807. His chief aim was to investigate the mining districts of Sweden and Southern Norway, and his account of the journey, which was published several years later, contains a large number of valuable observations on the minerals and ores of these districts. It also embraces detailed descriptions of the Cambrian rocks near Andrarum, the famous section at Kinnekulle, and other features of geological interest. Hausmann was the first scientific observer who noted the position of the granite *above* the "transitional" limestone formation in the neighbourhood of Christiania, and the first who described the zircon syenite of the Langensund (cf. p. 86).

But Leopold von Buch's *Journey to Norway and Lapland* (Berlin, 1810) was the work which first gave European geologists an insight into the general geological structure of Norway. The novelty of many of the districts traversed, and the author's genius for the narration of scientific observations, combined to secure immediate popularity for this work.

On the journey to Scandinavia, Leopold von Buch passed through Mecklenburg, Hamburg, Holstein, and Copenhagen. He gave full notes about the erratic blocks, and the white chalk of Möen and Stevensklint. The journey to Christiania was carried out by land, the route leading across the Swedish seaboard and the coast of the Christiania Fjord. Von Buch confirmed Hausmann's observation that not granite but gneiss was the predominating rock in this district. He was also greatly struck by the relations between the transitional rock-formations and the granite-grained rocks. He described the various kinds of rock, and showed that the porphyry penetrated the "transitional" formations as dykes and veins, and that between Drammen and Christiania a large mass of granite rested upon fossiliferous "transitional limestone." This occurrence was at once admitted by Buch to be incontestable evidence that granite was not, as Werner had taught, in all cases part of the oldest rock-formation, although he still clung to the idea of the aqueous origin of the porphyritic and granitic series. In 1808, Leopold von Buch travelled through the northern territories of Norway and Lapland. He took geological observations at the Dovre Feld Mountain in Drontheim, at Lake Mjösen,

and in Gulbrand Valley; and wherever he travelled he gave attention to the climatic conditions, and to the habits and cultivation of the people. Near the town of Drontheim, Buch saw a coarse-grained diallage rock, which he afterwards recognised again in the Alps of Valais, in Tuscany, the Riviera, and other places; he described it under the name of "gabbro." He observed the diallage rock together with slate at the North Cape. His numerous observations on upraised beach deposits round the northern coast-line of Norway led him to conclude that the uprise in Sweden had been greater than in Norway, and had been altogether greater in the north than in the south of the peninsula.

In Russia, the numerous remains of land mammals, especially the mammoth and rhinoceros, had long attracted attention. One of the chief aims of Johan Georg Gmelin's expedition to Siberia was to look for complete remains of these animals and bring them to St. Petersburg (*Reise durch Siberien*, 1752). Pallas was, however, the scientist who most successfully carried out this purpose, and his works were the means of opening up to science the geological structure of the vast Russian empire. The collective works of Georgi and Razumowsky, as well as the first geological map of Russia by Strangways, are largely based upon the researches of Pallas, and partially upon the independent investigations of these geologists.

G. *America, Asia, Australia, Africa.*—Although no country outside Europe bore any appreciable part in the construction of the early framework of the science, it was a matter of keen interest to geologists to compare the structures ascertained in Europe with those in other regions of the globe. All observations of the mineral constituents and structural forms in other parts of the world were much valued at home, and in many cases were employed as corroborative evidence in favour of one theory or another. In the beginning of the nineteenth century but little was known in Europe of the geology of foreign parts, yet what was known sufficed to show that the results obtained in Europe were in harmony with geological phenomena elsewhere, and might therefore be regarded as a sure scientific basis for future progress.

The errors, the false hypotheses, and bitter disputes which had retarded the growth of the science during many centuries

in Europe, were spared in the case of the other continents. In them the knowledge so hardly won in Europe could at once be adopted, and the help of experienced European observers could be secured in carrying out pioneer research elsewhere. Thus geological data furnished within a few years in foreign lands could often bear comparison with the results that had demanded many decades or even centuries of work in the European territories. Active co-operative research in the other continents did not commence until after the period with which this introductory chapter deals.

North America was first brought into the field of geological science. As early as 1752, Guettard had examined a collection of Canadian fossils, and had tried to apply to North America the sedimentary horizons which he had erected for Europe. He had gone so far as to construct a hypothetical map showing the distribution of the various rock-formations whose existence he had surmised.

Of another character were the investigations of the Scotsman, Maclure (1763-1840), who had been trained as a mineralogist by Werner. Maclure published in 1809 a treatise and a map on the geology of the United States (*Trans. Amer. Phil. Soc.*). He distinguished the rock-formations according to Werner's system, and showed that the primitive rocks predominate on the north and west of the Hudson, and form the basement in the New England States; the transitional formations repose upon the primitive rocks and extend far west to the Mississippi, where the Flötz or younger sedimentary formations begin. Maclure also gave a clear exposition of the distribution of the Carboniferous formation in the Alleghanies, in Pennsylvania, and in the West, of the absence of trap-rocks in the Flötz formation, and the absence of porphyry, vesicular rocks, and basalt in the whole eastern district of the United States. He fully realised and depicted the simplicity and the gigantic scale of geological structures in the United States.

Maclure's comprehensive survey of the geology of North America overshadows the many smaller works on local stratigraphical details, such as those of Jefferson, Gibbs, Bruce, Silliman, and others.

Long before geological research had begun in North America, however, the presence of mammalian remains similar to those of Siberia had been discovered. Dr. Mather, in 1712, reported in a letter to Woodward the presence of bones of enormous

size near Albany (New York), and surmised that they must have belonged to a race of giants. In 1739, a French officer, Longueil, brought back to Paris fossil bones and teeth found in a marsh near Ohio. Daubenton and Buffon identified the bones as Elephas and the back teeth as Hippopotamus remains. More complete fossil remains were discovered by Croghan and Peale, and the restoration of a skeleton was attempted. Cuvier, with his customary insight, recognised in this an extinct genus of Proboscidæ, to which he gave the name of Mastodon. His great work on Mastodon gives a full account of all the remains of this extinct genus that had been found up to that time in North America.

In a cave in West Virginia, Jefferson discovered along with Mastodon remains the extremities of another diluvial animal. Cuvier examined these, and referred them to a gigantic genus (Megalonyx) belonging to the Edentates.

Throughout Mexico, Yucatan, Bolivia, Peru and Chili, fossil bones of enormous size had been frequently found during the sixteenth and seventeenth centuries. In 1789, Loretto, the Regent of Buenos Ayres, sent a complete skeleton of one of these fossil animals to Madrid, and shortly after, two other skeletons were sent from Lima and Paraguay. These were described by J. Garriga under the generic name of Megatherium; they were found to belong to the Edentates, and, like Megalonyx, to the sub-order Gravigrada. Garriga's identification was afterwards confirmed by Cuvier. The first remains of a Glyptodon, another of these heavily-built fossil Edentates, are mentioned by the Jesuit Falkner in the account of his travels.

Alexander von Humboldt's observations were the earliest contribution to the geology of Central America. This great geographer applied Werner's system of rock-formations, and wherever he travelled in Central and South America identified the rocks in accordance with Werner's petrographical teaching. He thought that the distribution of the rocks in these regions fully confirmed Werner's chronological succession of the groups of formations.

In Asia, the pioneer work of Pallas in Siberia and the Urals was continued by Patrin, who published in 1783 the *Account of his Travels in the Altaï Mountains.* The geological structure of Central and Southern Asia, Australia, and Africa was still a blank at the beginning of the nineteenth century. The

few reports that had been given by travellers merely confirmed the presence of volcanoes in one locality or another, or mentioned the occurrence of the more striking varieties of rock.

Progress of Petrography—Neptunists, Volcanists, and Plutonists.—In the older mineralogical literature the rocks also received a passing notice. As a rule, authors limited these remarks to a description of their external features. Cronstedt removed them from this subordinate position, and paved the way for Werner's creative work in establishing the study of the rocks as an independent branch of Geognosy. Werner's classification and description of rock-varieties, published in 1786, comprised all existing knowledge of rocks, and replaced the vague conceptions of former years by a series of exact definitions and the introduction of a new, precise nomenclature. Werner distinguished simple and composite rocks; the former were discussed both as minerals and rock-forms, *e.g.* quartz, gypsum, salt, etc., the latter were identified and classified according to their mineralogical composition and their age, *e.g.* granite, basalt, sandstone, marl, etc.

Each rock was defined in respect of its texture, stratigraphical position, jointing, age, origin, and occurrence. In the case of composite rocks, the *essential* components were distinguished from the *accessory* and the rock was classified solely upon the ground of the *essential* components.

The rapid advance of petrographical knowledge during the first two decades of the nineteenth century was undoubtedly the direct result of Werner's precise methods. All observers during those decades gave marked attention to the determination of petrographical features. Saussure's descriptions of the crystalline massive and schistose rocks in the Swiss Alps can scarcely be surpassed. Monographs appeared from time to time on special varieties of rock. Faujas de Saint-Fond, for example, wrote a monograph on the "trap-rocks," in which he showed how loosely this name had been applied in the literature, so that rocks of many different kinds were embraced under it.

Ferber and Dolomieu investigated the volcanic products of Southern Italy. Desmarest, Faujas, and others examined the Egyptian porphyries and so-called basalts. Leopold von Buch introduced the name of *gabbro*, and described *leucite*

lavas and *trap-porphyry* (trachyte) in detail; while Hauy introduced the names of *pegmatite*, *diorite*, *trachyte*, *aphanite*, *euphotide*, *leptinite*.

Brongniart attempted a complete classification of rocks in 1813, and introduced the terms *diabase*, *melaphyre*, *psammite*, etc. Fleurien de Bellevue and Cordier made use of the microscope for the identification of the components in powdered specimens, but with little success.

The advances made in these early decades practically represented the progress that could be attained by the use of Werner's method. A new era began for this branch of geology when, in later years, the microscope was applied to the examination of thin rock-sections by transmitted light.

Very great interest centred round the origin of the massive crystalline and schistose rocks, and widely divergent opinions were held. The Neptunists thought that all rocks, with the exception of products from active volcanoes, were of aqueous origin. At first the Neptunists and Volcanists disputed only the origin of basalt, which Tobern Bergman, and afterwards Werner and his school, regarded as a sedimentary rock. Almost all French geologists had studied basalt in Auvergne, Velay, Vivarais, or in Ireland, and adopted the view of Desmarest and Faujas de Saint-Fond, that basalt was a volcanic product.

In Germany, Werner's personal influence kept alive Neptunian doctrines even against sharp attacks like those of Voigt (p. 83). Not a few of the German geologists began to assume an intermediate position. Beroldingen tried to unite the opposite opinions by suggesting that basalt owed its origin to volcanism, but its form to water. The basaltic magma had solidified on the bed of the ocean, and its pillared, sheet-like, spheroidal, or crystalline form had been developed under the influence of water and hot vapours. In favour of this view, Beroldingen cited the local occurrence of Ammonites, Gryphites, and Belemnites in basalt. This observation was, however, afterwards found to have been erroneous. Yet in the course of his discussion, Beroldingen gave expression to many valuable remarks about volcanic ejecta and the disintegrating changes undergone by volcanic rocks. C. W. Nose, an observer who greatly advanced the geology of the Lower Rhine provinces of Prussia, was of the opinion that basalt and porphyry originated as sedimentary deposits, but were

subsequently more or less altered, sometimes even fused and rendered glassy or slaggy.

When, after Werner's death, his two most famous pupils, Leopold von Buch and Alexander von Humboldt, declared themselves in favour of the volcanic origin of basalt, the defeat of the strict Neptunists was sealed. A historical account of the whole question of basalt, and the disputes between Neptunists and Volcanists, may be read in Keferstein's *Contributions to the History and Knowledge of Basalt* (1819).

But Neptunian doctrines still continued to be accredited for granite, syenite, gneiss, and other members of the holo-crystalline series. Descartes, Leibnitz, and Buffon had certainly explained the primitive earth-crust as the result of cooling from a molten mass, but they had made no attempt to explain the origin of the various kinds of primitive rock. It was generally supposed that granite, gneiss, schist, porphyry, phonolite, and similar rocks were chemical precipitates separated from a primitive ocean strongly impregnated with mineral substances. Therefore Von Fichtel, writing in the end of the eighteenth century, showed an exceptionally enlightened spirit among German geologists when he included not only basalt but all granitoid, gneissose, schistose, and doleritic series as igneous in their origin. Fichtel distinguished two kinds of volcanic mountains—(*a*) those which consist of immense uniform masses, sometimes building up a whole mountain-chain, and (*b*) those in which rocks of different constitution alternate with one another in a stratified way (lava, ashes, rapilli, etc.). He described the homogeneous masses as having risen without any violent phenomena of eruption, and having penetrated the crust at the places of least resistance; whereas the others were produced by successive eruptions, during which the ejected material gathered in conical form round the craters of eruption.

But the great founder of the Plutonic school was James Hutton. According to Hutton, heat is the most powerful agent in the origin of rocks. The heat that pervades the lower horizons of the crust converts all rock-material into a molten magma. Under the superincumbent weight of the younger sedimentary rocks and the ocean, mineralogical combinations can take place which would not be possible at the surface under conditions of normal pressure and rapid cooling. The primitive schists and limestones have been produced from a

molten mass in this way; granite, porphyry, trap, basalt, and similar rocks were pressed up by subterranean heat, but did not reach the surface; they were intercalated as subterranean eruptive masses partially between pre-existing sedimentary rocks, or they spread as extensive sheets of rock-magma on the ocean-floor. Notwithstanding the strong support given to Hutton's theory by his friends and adherents, Hall, Playfair, and Watt, the theory of the Scottish genius found little recognition in his life-time. The Plutonic doctrines were slow to plant their roots in geological literature, and it was not until the third decade of the nineteenth century that they were universally accepted.

Palæontology.—The first two decades of the nineteenth century, which were remarkable for the great advances in petrography, were less fruitful in the domain of palæontology. In Germany, the Wernerian school was almost wholly absorbed in the study of rocks, and the petrified remains of plants and animals were in a measure neglected. The splendid work of Walch and Knorr had been followed by Schröter's *Introduction to the Knowledge of Rocks and Fossils*, the value of which rested chiefly upon its bibliographical merits (1774-84).

The famous Göttingen zoologist, Blumenbach, published in 1803 and 1816 two short treatises on fossils. He sub-divided fossils into four groups: (1) Fossils identical with existing species still represented in the same localities where the fossil forms existed; (2) fossils identical with existing species, but not with those at present inhabiting the particular localities where the fossils occur; (3) fossils indicative of some great climatic change in the localities where they are found—*e.g.*, cave-lion, rhinoceros, etc., which resemble but are not identical with living species; (4) marine fossils belonging to extinct species, and showing that the earth was once covered by the ocean.

It seems surprising that such crude and superficial conceptions of fossil groups should have been formulated by a zoologist of the reputation of Blumenbach, yet such was his fame that his opinions received far more attention than they deserved.

Baron Ernst von Schlotheim (1764-1832) was one of the few adherents of Werner who devoted himself to the study of fossils. His first work, published at Gotha in 1804, was a

monograph of the plant impressions in the Carboniferous formation on the Thuringian districts, and was quite the best work on fossil plants that had appeared. Schlotheim concluded that, in spite of the resemblance between the tree-ferns of the Carboniferous formation and certain East Indian and American ferns, the fossil types belonged to extinct genera and species. The same was, he said, true for the other forms of Carboniferous plants, and it was possible that the fossil flora of the Carboniferous epoch represented a *wholly extinct plant-world.* Schlotheim left it an open question whether, in this case, the fossil genera had died out, or whether their descendants had become so much modified that they could scarcely be recognised as such.

Schlotheim's later work, his *Petrefaktenkunde*, published in 1820, enumerated and described the fossil specimens in his private collection. At the same time, in its plan it formed a continuation of his previous work, and the fifteen quarto plates of the Carboniferous flora were incorporated, together with twenty-two new plates, to illustrate the larger work. The plates were admirably carried out, and the specimens, which included all types of animal life, were for the first time in Germany named according to the *binomial nomenclature.* Hence the work has had a permanent value in literature, although it is true the descriptive text is often insufficient, and a species can be identified only by comparison with Schlotheim's originals, which have been preserved in the Berlin Museum.

Faujas de Saint-Fond's works on fossil organisms can scarcely be compared with those of Schlotheim. The first volume of his *Essay on Geology* (Paris, 1803) is devoted almost exclusively to fossils. But he held the narrow, antiquated opinion that the great majority of fossil forms represented existing species of plants and animals, while the few forms for which no living analogues were forthcoming probably belonged to species now living in unexplored portions of the globe.

Defrance was one of the most industrious and careful of the early palæontographical annotators. In his *Sketch of Fossil Organisms* (Paris, 1824) he gave a short account of all known fossils, with accurate mention of their localities and state of preservation. Between 1816 and 1830 he contributed to the *Dictionary of Natural Science* numerous treatises on fossil foraminifers, corals, molluscs, annelids, and echinids.

In England, with the exception of Woodward's "Catalogue" of the collection now preserved in Cambridge, there was no general work on fossils. James Parkinson tried to supply this deficiency in his work, *Organic Remains of a Former World* (1804-11); the epistolary style was selected as the most easy of comprehension, and the most likely to stimulate popular interest in fossils. The first volume gave in forty-eight letters a short history of palæontological knowledge, an account of the various views about fossils or "Medals of Creation" (a name which Parkinson and others had adopted from Bergman), and a discussion of the surface forms and physical constitution of the earth. Peat, lignite, brown-coal and coal, buried woods, bitumen, etc., were then described according to their properties, their mode of occurrence, state of preservation, and the changes they had passed through. The various fossil woods, leaf-impressions, ferns, stems, branches, and fruits belonging chiefly to Carboniferous and Tertiary times were enumerated and compared with existing types; nine coloured quarto plates complete this volume.

Parkinson shared in great measure the older conceptions of the "diluvialists" about the origin of fossils; the comparison of fossil and living forms, which he carried out in collaboration with the botanist, J. Edward Smith, led him to the conclusion that the most of the fossil plant types were the products of a warmer climate. Parkinson unfortunately made no attempt to identify the fossil plants according to genus and species, nor did he use the Linnæan method of nomenclature. Hence his work on fossil plants is distinctly behind the almost contemporaneous publication of Schlotheim.

The second volume treats of corals, sponges, and crinoids, and comprises twenty-nine letters and nineteen plates. The Linnæan method of nomenclature was introduced into this volume, but was not carried uniformly through the work. In the third volume, with 22 plates, Parkinson had the advantage of fuller reference literature. He could refer to the works of Klein and Leske on Echinoderms, to the writings of Lamarck on Molluscs, to the result of Cuvier's investigations on Vertebrates. We find the author's views considerably expanded in this volume, wherein he becomes more and more convinced that numerous fossil species belonged to extinct forms of life. Moreover, the influence of William Smith's researches had spread amongst English geologists, and taught

them the chronological succession of the strata. Parkinson finally expressed his belief that the Mosaic account of Creation could only be accepted in its general intent, that the "days" of the Biblical account in reality indicated very long periods of time in the development of the earth. A summary of Parkinson's work was afterwards published under the title of *Outline of Oryctology* (London, 1822).

While these were the more representative works on palæontology which appeared in Germany, France, and England during the early decades of last century, numerous papers on special fossil genera or local faunas were published in scientific memoirs and journals. A few of the more important works devoted to the various animal types may be mentioned.

In the class of Protozoa, fossil *Nummulites* had been known to the ancients. Herodotus had mentioned their occurrence in Egypt, and Strabo had compared them with lentils. Conrad Gesner (1565) described the first Nummulites known in Europe; they were found in the neighbourhood of Paris, and referred to the Ammonites. Aldrovandi regarded them as sports of nature, and Kircher described them under the name of "caraway" or "cummin" stones. Good descriptions and illustrations of Swiss Nummulites were given by Scheuchzer and Lang, and after that time they were included in all collective works on fossils under various names—discoliths, helmintholites, helicites, nummulites, lenticulites. Special papers were written upon them, but authors failed to arrive at any clear understanding about their zoological position. As a rule they were associated with Nautilus and the Ammonites, but they were sometimes regarded as worms (De Saussure), or as the inner shells of molluscs (Fortis, De Luc).

In 1711 J. B. Beccari discovered the first small fossil *foraminifers* in the Tertiary sand of Bologna, and compared them later (1731) with the small shells found by Janus Planchus (Bianchi) on the beach of Rimini. In 1791 Soldani published his excellent work on the foraminifers from the Tertiary strata of Siena; the figures show the specimens many times enlarged. Fichtel and Moll prepared a monograph, with twenty-four coloured plates, showing all foraminifers known up to 1803, the date of publication, and Batsch gave a number of clear illustrations of different genera and species. Nothing was known about the soft parts of the foraminifers; the whole literature confined itself to the description and classification of the shells.

Good illustrations of *sponges* appeared in the pictorial works of the seventeenth and eighteenth centuries, but they were generally termed pelagic plants or fruits, or were included with corals and bryozoa, under such names as coralliolitbs, alcyonias, fungites.

Guettard was the first to publish a more detailed investigation of fossil sponges. His researches were not confined to the description of external features, but made a careful note of the inner construction, the canals and openings. At first Guettard rightly compared the fossil specimens with existing sponges, afterwards he placed them with corals, but ultimately returned to his first idea that they were sponges. His treatises are accompanied by good figures, and undoubtedly rank as the best contributions to the older literature. Parkinson included the fossil sponges with alcyonarians; he gave careful descriptions and very good illustrations of a number of Cretaceous and Jurassic forms, but made no attempt at systematic treatment; in his later, smaller work, Parkinson compared some forms with sponges, others with alcyonarians, and Schlotheim took much the same standpoint.

Fossil *corals* were figured by Knorr and Walch, and by most of the early writers on palæontology. Linnæus gave the Silurian coral fauna of Gothland to one of his students, Fougt, to be described, and Guettard published detailed works on fossil corals from the Dauphiné and other parts of France. The fine illustrations of Parkinson represented more especially the coral types of the older strata in England and Scandinavia. Schlotheim also described a large number of species under the vague generic titles of Fungites, Porpites, Hypurites, Madreporites, Milleporites, and Tubiporites. On the whole, the study of fossil corals was limited to external features; little was known about the organisation of recent corals, and the systematic arrangement had no secure basis.

The knowledge of *crinoids* had reached a more favourable stage of advancement. The older authors in the sixteenth and seventeenth centuries occasionally figured the stems and crowns of crinoids under the terms of trochite, entrochite, encrinus, pentacrinus, or under such popular terms as fossil "wheels," "lilies," "pennies," etc. The classificatory position of fossil crinoid remains continued, however, quite indefinite until Rosinus in 1718 demonstrated their affinities with existing representatives of the *Euryaleæ*, an Ophiuroid family. Rosinus

in his treatise proved conclusively that the fossil crinoid stems were not independent individuals, as had been erroneously supposed, and gave complete representations of several genera, more especially of the genus Encrinus.

The first example of a living Pentacrinus came from Martinique, and was described by Guettard, who fully recognised the relationship of the recent species with earlier forms in the Liassic and Jurassic strata.

Schulze and Parkinson added valuable data to the investigation and relationship of sea-lilies, as the crinoids were commonly designated; while Blumenbach classified them in near relationship to the ophiuroids (brittle-stars) and asteroids (star-fishes). But the founder of the more scientific literature of crinoids was Miller of Danzig, who published in 1821 his famous work, *Natural History of the Crinoidea or lily-shaped Animals.* Miller not only gave admirable descriptions of a number of previously unknown species from the Carboniferous limestones of Ireland and the Upper Silurian limestones of Dudley, but also proposed a clear terminology for the individual parts of the calyx, the arms, and the stem or column.

In the case of the important class *Echinoidea* (Sea-Urchins), contributions to the literature of fossil and existing forms practically kept pace with one another. The first systematic treatment of the *Echinoidea* was published as early as 1732 by John Philip Breyn of Danzig. In his work all known living and fossil forms were grouped under seven genera. Two years later Klein's *Dispositio Echinodermatum* appeared, and Leske in 1778 prepared a second and enlarged edition of this important work. The Klein-Leske classification recognised twenty genera, the names of which have only been partially continued in the literature. The works of Breyn and Klein have both sustained their reputation in zoological and palæontological literature.

Fossil molluscs were always awarded a large amount of attention owing to the remarkable number of species, the wide range of distribution and favourable preservation of the shells. Fossil cephalopods were figured in the older works of the seventeenth and eighteenth centuries, as a rule under the names of belemnites, nautilites, ammonites, and orthoceratites. The Gastropods or Snails were sub-divided into numerous genera of somewhat indefinite characters—*e.g.*, Dentalites,

Patellites, Volutites, and others; the Mussels or Conchifera with which Brachiopoda and Cirripedia used to be included, were grouped under various generic names—*e.g.*, Myacites, Tellinites, Pectinites, Gryphites, etc. Brachiopods were termed "conchæ anomiæ" or "Anomites," following the precedent of Fabio Colonna.

The *Systematic Conchology* of Denis de Montfort (1808-10) contained several new genera, chiefly of cephalopods, but the descriptions were extremely meagre. The more meritorious work of Bruguières, in the *Encyclopédie Méthodique*, on living and fossil molluscs and brachiopods, was unfortunately cut short by the premature death of the author.

Lamarck[1] was the great reformer and founder of scientific conchology. He published in the *Annales du Muséum* a monograph of the Tertiary mollusca of the Paris basin, with a good series of plates; and in his *Natural History of Invertebrate Animals* he defined the numerous genera and species of invertebrate animals with masterly skill and precision, and laid down, more especially for mollusca, a systematic basis which held its place for several decades.

Another work, almost as important for the knowledge of fossil mollusca, although of far less scientific depth than Lamarck's, was the *Mineral Conchology of Great Britain*, begun by James Sowerby in the year 1812, and completed by his son, James de Carle Sowerby, between 1822 and 1845. It is an illustrated catalogue of all the fossil mollusca occur-

[1] Jean Baptiste de Monet, Chevalier de Lamarck, born 1744 at Buzantin, near Bapaume (Somme), distinguished himself early in the army career which he had chosen, but was wounded and had to take up another calling; he then studied medicine, working in a bank to provide a means of livelihood, and devoted himself with enthusiasm to botany, physics, and chemistry. In 1773 he published a *French Flora*, in 1778 was appointed Custodian of the Botanical Gardens, and when he was in his fiftieth year was elected to the Professorship of Zoology in the Museum, an appointment which he held until his death in 1829. In 1801 he published his *System of Invertebrates*, and between the years 1815-22 his greatest work, the *Natural History of Invertebrate Animals*. A second edition of this work appeared in 1836, with additions by Deshayes and Milne-Edwards. In his *Philosophy of Zoology*, Lamarck gave all the weight of his knowledge and experience to the support and elucidation of the Theory of Descent and Specific Variation. As is well known, Lamarck held that acquired characters could be transmitted to descendants, and become permanently established in the race. These ideas met at first with great opposition, and only received support in more recent years. His adherents at the present day form the so-called Neo-Lamarckian school.

ring in Great Britain. The six volumes appeared in parts, and comprise 604 cleverly-drawn coloured plates with explanatory text. The material is not arranged in any systematic order, the descriptions and figures have clearly been prepared in the succession in which the specimens came into the hands of the authors. A work of this character could not have a very high scientific value, yet both the Sowerbys were indefatigable collectors, good conchologists, and expert draughtsmen, and their work did much to advance the study of fossils.

Among the monographs that appeared about this time, one of the best was J. C. M. Reinecke's *Monograph of the Ammonites occurring in Coburg and Franconia* (1818), a work describing and figuring forty species of cephalopods from the Jurassic and Triassic limestones of that area. Another valuable local work was that of Brocchi on the Tertiary mollusca of Italy, *Conchyliologia fossile subapennina* (Milan, 1811).

Very little was known about fossil *Arthropods* up to the year 1820. Fossil crabs had been found in the lithographic shales of Bavaria and the Tertiary strata of Upper Italy and Tranquebar; trilobites had been found in England, Sweden, and Bohemia, and occasionally insects had been recognised and figured in the older palæontological works. But no thorough scientific investigation of any group of arthropods had been undertaken.

Fossil *Fishes* play a not unimportant *rôle* in the history of geology and palæontology. The teeth of sharks had led Palissy and Steno to correct conceptions about the significance of fossils, and the early observations on fossil teeth were incorporated in all great works on the rocks. Most of the names given to them were fanciful—*e.g.*, "serpents' tongues," "birds' tongues," "swallow stones"; of the more learned terms, "glossopetra" and "lamiodonta" were the most usual.

Impressions and skeletons of fishes were sometimes found in an excellent state of preservation in the copper slate of the Mansfeld district, in the Jurassic shales of Solenhofen and Eichstätt, the calcareous marls of Oeningen, the black slates of Glarus, the Tertiary calcareous shales of Monte Bolca, and in other localities. Volta published in 1796 a splendidly illustrated monograph of the fossil fishes of Monte Bolca. Faujas de Saint-Fond, in his *Essay on Geology*, and later Blainville in his *Dictionary of Natural History* (1818), gave a

summary of the known species of fossil fishes and the localities in which they occurred.

Few specimens of *Amphibians* had been discovered; the famous "Andrias" of Scheuchzer and a few remains of frogs in the Oeningen beds were almost the only representatives known in the literature.

Reptiles also were only known by rare specimens. Ichthyosaurian vertebræ from the Liassic strata of England and Altdorf had been figured by Lhuyd and Baier as fish vertebræ, whereas Scheuchzer had taken similar specimens from Altdorf for human vertebræ. Sir Everard Home gave the first description of an ichthyosaurian skull from the Lias of Lyme-Regis under the name of Proterosaurus (*Philos. Trans.*, 1814). One of the most ancient reptiles, the Triassic Proterosaurus from the copper slate of Suhl, had been found as early as 1706, and in 1710 had been assigned to the group of crocodiles; a second specimen was again described in 1718 by Linck as a crocodile, but Kundman thought it bore a stronger resemblance to lizards, and this was the view afterwards confirmed by Cuvier.

True crocodile remains were mentioned by Collini from the Liassic strata of Altdorf, and by Faujas de Saint-Fond from the Upper Jura of Honfleur and Le Havre and the Tertiary rocks of the Vicentine. In the Upper Lias of Whitby a full crocodile skeleton (Teleosaurus) from five to six feet long was seen by Chapman and Wooller, but only a few of the vertebræ could be saved entire (*Philos. Trans.*, vol. 50).

The discovery of a Mosasaurus skull in the Cretaceous tuffs of Petersberg, near Maestricht, has already been mentioned, and its identification by Cuvier as a lizard (*ante*, p. 107).

A great sensation was produced when, in the Jurassic shales of Solenhofen, a complete skeleton of a perfectly preserved small saurian was found with wing-like appendages. Collini described and figured it as an unknown marine animal of doubtful zoological affinities. Blumenbach regarded it as a water-fowl, but Cuvier recognised the skeleton as essentially reptilian in structure, called it *Pterodactylus*, and described it as a flying reptile. Although Cuvier had given convincing data for this conclusion (in his *Researches on Fossil Bones*, vol. iv., 1812), Hermann and Sömmerring explained the skeleton as that of a mammalian genus allied to the bats. The original specimen is now in Munich Museum.

All known fossil reptile forms were included by Cuvier in his *Researches*, and were fully discussed by him in respect of their own characteristic features, and their affinities to living genera.

Among fossil *Mammalia* the teeth and bones of elephants first attracted attention and gave occasion to various hypotheses. Fossil ivory and large bones were known to the Greeks and Romans; Suetonius reported on fossil "giant bones" in the Museum of Emperor Augustus at Capri, which probably were remains of fossil elephants. Kircher and many other authors in the Middle Ages mentioned the occurrence of elephant remains in different parts of Italy. A whole skeleton was unearthed at Crussol in the Rhone Valley in 1456, and a second in the Dauphiné in 1613. The latter won great notoriety. A surgeon, Mazurier, said it was the skeleton of Teutobochus, King of the Cimbers, and made money by the display of individual bones in Paris and other cities. It then became the subject of a heated controversy between Habicot and Riolan; Habicot holding the bones to be those of a man, Riolan asserting the bones were those of an elephant. As time went on, frequent discoveries of large bones were made in France, Belgium, and Germany.

The skeleton found at Burgtonna in 1696 was one of the most famous discoveries, as it gave rise to a dispute between Ernst Tentzel and the medical faculty in Gotha. The other professors saw in the large bones only sports of nature, but Tentzel proved to their discomfiture that the bones were real, and had belonged to elephants. In 1700 a bed of fossil bones was observed near Cannstatt, containing astonishing numbers of elephants' teeth, some of which have been preserved in the Stuttgart Museum. Pallas had made known the occurrences of mammoth bones in Russia and Siberia; and in 1796, Cuvier summarised all the previous literature on this subject in a brilliant treatise on fossil elephants. Blumenbach was the first author who distinguished the fossil elephant or "Mammoth" under the term *Elephas primigenius* from the two existing species.

Another fossil mammal which received considerable attention was the woolly-haired *Rhinoceros antiquitatis* or tichorinum. Pallas had in 1772 described a completely preserved carcass with hide and flesh in the frozen ground of Siberia. Skulls and other remains of this species were also found in

the Rhine Valley. Faujas de Saint-Fond tried to prove, in opposition to Cuvier and Blumenbach, that these were identical with the bones of species still existing in Africa.

The Franconian caves were examined by Esper and Rosenmüller, and the mammalian remains found in them were thoroughly investigated. The remains of Mastodon and Megalonyx, as well as other gigantic mammalia of America, were quite well known to Buffon and several writers in the eighteenth century.

But almost all publications on fossil mammalia had been founded on a very insecure scientific basis, and had not attained to any satisfactory result regarding the affinities of the fossil to the living forms. It was the creative genius of Cuvier[1] that erected Comparative Anatomy into an independent science, and defined principles upon which the investigation of fossil Vertebrates could be carried out with accuracy.

Cuvier's papers on fossil Vertebrates, which originally appeared in the *Annales du Muséum*, were collected in 1812 and compiled into a separate work, the papers being arranged merely in the order of their publication.

Cuvier's *Researches on Fossil Bones* was published as a four-volume work. The first volume contains the famous "Preliminary Discourse," which was really written later than the contents of the other three volumes, although all were published together in 1812. The "Discourse" was frequently altered by the author, and ran through six editions. It will be more fully discussed below. The second volume of the *Researches* begins with some remarks on the sub-divisions of the *Pachydermes* (Cuvier) among *Ungulates*, and on the deposits in which their fossil remains occur. The account of the *Pachydermes* is followed by a series of studies on the comparative osteology of Hyrax, the fossil and recent walruses, hippopotami, tapirs, and elephants, also the extinct genus Mastodon. The text

[1] Leop. Chr. Friedr. Dagobert Georges Cuvier, born on the 24th August 1769 in the town of Mömpelgardt (Montbeliard), which then belonged to Würtemberg, was educated at Stuttgart in the "Karl Schule." In 1788 he became tutor to Count d'Héricy at Fiquainville (Calvados); in 1795, Professor at the Central School in Paris; in 1800, Professor of Natural History at the College of France; in 1802, Professor of Anatomy at the Botanical Garden. Honours were richly showered on him: in 1814 he was made a Councillor of State; in 1819, Chief of a Department in the Home Office with the title of Baron; and in 1831 a Peer of France. He died on the 13th May 1832.

gives clear indication of the constructive methods adopted by the great anatomist. We follow him in his attempts to identify the remains of fossil mammalia by comparison with existing mammalian species, and we realise with him the necessity of a thorough examination of the bony skeleton of existing mammals before such a comparison can be effected. Cuvier's style is clear and concise, and he has the gift of vivid description.

Eleven fossil species from the Pleistocene deposits of Europe, Asia, and North America are described in the second volume: a rhinoceros, two hippopotami, two tapirs, an elephant, and five mastodons. With the exception of the mastodons, all the species belong to genera which still exist in the tropics, but the geographical distribution of the Tertiary and the present species is very different. There may be a doubt in the case of the larger hippopotamus species (*Hippopotamus major*) whether the fossil and the present forms are specifically distinct, but in the other cases there can be no doubt that the forms belong to extinct species.

Cuvier makes these points clear, and proceeds to show that from the condition of the bones they cannot have been transported from any great distance, but that the animals must have *lived in the localities where their bones are found.* Hence these remains afford proof that the temperate zones were, in the period immediately antecedent to the present, inhabited by a terrestrial fauna whose nearest allies are now confined to tropical climates.

The third volume contains chiefly the description of the vertebrate remains which occur in Upper Eocene gypsiferous marls, in the vicinity of Paris. One or two fossil skeletons were found entire, and most of these remains found in the Paris gypsum beds were in a good state of preservation. But in many localities the mammalian remains occurred in poor preservation, and were irregularly distributed as confused heaps, or beds of bone fragments. It was in arranging such ill-assorted accumulations of bones belonging to different epochs that Cuvier achieved his most astonishing successes, and verified his laws of the correlation of parts. The investigation of certain scattered remains of very frequent occurrence led him to the determination of two extinct genera, *Palæotherium* and *Anoplotherium*. After he had ascertained the skull and teeth, Cuvier kept constantly comparing the other bones with those of existing genera—tapir, rhinoceros,

horse and camel,—and was finally able to restore the skeletons of these extinct genera. Then it became evident that both genera had comprised several species, and gradually the fossil remains of other genera intimately allied to these were discovered in the Middle and Upper Eocene strata at Issel (Aude), Buchsweiler (Alsace), and in the Upper Eocene marls in various localities. In the same way as he had investigated the *Ungulata*, Cuvier also investigated fossil remains belonging to Carnivora, and determined their relationship with living representatives.

Cuvier was wholly convinced of the unerring accuracy of his comparative methods. It is told of him that on one occasion when a fossil skeleton came into sight in the Paris gypsum layers, he at once declared it to belong to the genus *Didelphys*, an American opossum. A number of his colleagues were sceptical of this, and in order to prove it, Cuvier indicated the exact place where the characteristic marsupial bone on the pubis ought to be found in the rock, and in presence of his colleagues worked out the part from the surrounding rock, and displayed it to their astonished eyes.

The third volume concludes with the description of a number of bird, reptile, and fish remains. The fourth volume contains treatises on the remains of horses, pigs, and rodents in the Pleistocene deposits and bone breccias of Gibraltar; on Carnivora in the bone caves of Germany and Hungary; on some genera of the Edentate Order, Bradypus, Megalonyx, Megatherium; on Sirenia or "sea-cows"; on "sea-dogs" or the Phocidæ family of the Carnivora; and finally, a survey of all known fossil reptiles. In this as in the other volumes, every chapter on fossil types is preceded by an exhaustive exposition of the structures of allied living forms.

In the whole literature of comparative anatomy and palæontology there is scarcely any work that can rank with this great masterpiece of Cuvier. It passed through four editions, each edition containing additional chapters. The last (1834-36), edited by his brother Friedrich Cuvier, consists of ten volumes of text and two volumes of illustrated plates.

The "Preliminary Discourse" of the first volume later bore the title of "Discourse on the Revolutions of the Surface of the Globe," and was translated into several European languages. In it Cuvier gives expression to his views on the origin and

changes of the earth, on the relations of fossils to the present creation, and on the whole sequence of life in the course of geological epochs.

The Discourse begins with a demonstration that the surface of the earth has been devastated from time to time by violent revolutions and catastrophes. Cuvier argues that these took place suddenly, from the evidence of the flesh carcasses of mammalia in the gravels of Siberia, as well as from the accumulations of pebbles and *débris* which are present at certain horizons of the stratigraphical succession, and may be assumed to indicate epochs of violent movement in the former seas. Thus the development of organic life was frequently interrupted by fearful catastrophes, which in the earlier epochs extended over the whole surface of the globe, but latterly became limited to smaller areas. Countless living creatures fell victims to these catastrophes; they vanished for ever, and left only "a few remains scarcely recognisable by the scientific investigator."

A discussion of the natural forces which at the present day affect earth-surfaces leads Cuvier to the conclusion that these are *not* sufficient to explain the great revolutions of past epochs in the earth's history. The present agencies of ice and snow, running water and the ocean, volcanoes and earthquakes, together with disturbing astronomical conditions, are passed in review, for the purpose of demonstrating the insufficiency. Then Cuvier recalls the often ridiculous theories that philosophers and geologists invented in their endeavour to arrive at some adequate explanation of the great transformations of life and climate on the globe. He recognises the value of the mineralogical work of Saussure and Werner, but complains of the small share of attention bestowed by these geologists and their contemporaries upon fossils and the distribution of fossils in the rock-strata. Yet, in his opinion, it is the study of the fossilised remains of former faunas and floras which alone can give enlightenment about the earth's past, the number and order of its revolutions, and the history of creation.

He regards the remains of four-footed animals as especially valuable, since in their case the question whether they belong to extinct or living genera and species can be more definitely determined than in the case of the lower animals. Even in the days of antiquity men knew fairly well all the kinds

of four-footed animals on the globe, and at the present day there is little chance of new living species being discovered. Certainly the incompleteness and often poor preservation of the fossil remains of land mammals offered obstacles to exact identification. But they could be surmounted with the help of the laws of correlation enunicated by him, according to which all the individual parts of an organism stand in a definite morphological relationship to one another, so that one part could not undergo a change without a corresponding modification taking place in the correlated parts.

Summarising the results of his own researches on fossil bones, Cuvier shows that these occur in strata of different age, that the fishes, amphibians, and reptiles existed before mammalia, that the extinct genera (*Palæotherium*, *Anoplotherium*, etc.) occur in older strata than the forms belonging to living genera, and that the few fossil forms which differ little from living species are restricted to the very youngest deposits in river alluvium, marshes, caves, etc.

The exact investigation of fossil mammalia gives, according to Cuvier, no ground for the Lamarckian conception that the forms still existing have been produced by gradual modifications of the forms that had previously existed. On the contrary, Cuvier's conception was that *specific features are constant, and remain so even in domesticated breeds.*

Regarding the length of period during which man has existed on the globe, Cuvier points out that no human remains have been found along with the latest accumulations of four-footed animals in Europe, Asia, and America, and that in all probability man did not make his appearance in those parts of the globe until after the last great world catastrophe. And although no exact determination of the time is attainable, Cuvier calculates from data of the rate of increase in sand-dunes, in the thickness of peat deposits, and river deltas, that the last great earth's revolution took place not more than 5000 or 6000 years ago. Large parts of the terrestrial surfaces of the globe were then submerged, and the floor of the former ocean was in many places upraised and re-constituted as islands and continents. Some few human beings who were not destroyed during this catastrophe wandered into the new lands and multiplied, founded colonies, erected monuments, collected facts of natural history, conceived scientific systems.

In conclusion, Cuvier draws attention to the rudimentary state of scientific knowledge regarding the Secondary rocks and the fossil organisms contained in them. "How glorious it would be if we could arrange the organised products of the universe in their chronological order, as we can already do with the more important mineral substances! The knowledge of the order of successive forms of life would teach us about the organisation itself. The chronological succession of organised forms, the exact determination of those types which appeared first, the simultaneous origin of certain species and their gradual decay, would perhaps teach us as much about the mysteries of organisation as we can possibly learn through experiments with living organisms."

When we at the present day pass in retrospect the contents of Cuvier's famous "Discourse," it is easy for us to perceive that the great anatomist was not familiar with the more advanced geological thought of his own time. The works of William Smith were apparently unknown to him, equally so the researches of Lehmann, Fichtel, and other of the best German stratigraphers. In the structure of mountain-systems, his views differ little from those of Buffon, Pallas, and Saussure. What is new is that Cuvier demands a *great number* of catastrophal revolutions, and he assumes that the earlier catastrophes were more widespread in their effects than the later.

In supposing that an invasion of the sea was the immediate cause of the interment of mammalia in the youngest clays and gravels, Cuvier entirely misses the significance of the fact that these are for the most part of fresh-water origin. Again, his calculation of the age of the latest revolution and the appearance of man in the northern hemisphere betrays a geological standpoint as narrow as De Luc's or Kirwan's. But what was a far more serious disadvantage to science was that a man of Cuvier's anatomical insight and prescience should deny any genetical connection between the earlier organisms and those now living. Cuvier's erroneous convictions on this point exerted an enormous influence, and it is not too much to say that they retarded the progress of the evolutionary aspect of palæontology for several decades.

But Cuvier, by his teaching of the comparative methods, placed all-powerful tools in the hands of scientific men. His greatness rests upon the magnificent work that he accomplished in the domain of the Vertebrates, upon the scientific method

which he founded for the identification of fossil bones, and upon his successful demonstration that the primeval mammals were not mere varieties of living forms, but belonged to extinct species and genera.

As Buffon had done twenty years earlier, Cuvier likewise, by his commanding personality, attracted many to the study of geology and palæontology, and instilled enthusiasm into a large circle of his more intimate friends and scientific disciples. Others had shown how important fossils were for an understanding of the stratigraphical succession. But never before Cuvier had the significance of fossils been so energetically brought forward as a means of arriving at a true appreciation of animal skeletal structures, and of building up a history of the whole animal creation. Thus Cuvier largely contributed to the rapid progress that was made during the next quarter of the century in the detailed investigations of fossil organisms and their stratigraphical position.

It is not surprising that Cuvier's Catastrophal Theory, which afforded a certain scientific basis for the Mosaic account of the "Flood," was received with special cordiality in England, for there, more than in any other country, theological doctrines had always affected geological conceptions. Many of the best known English geologists—Greenough, Babbage, Sedgwick, and others—considered the "Flood" the latest of Cuvier's "World-Catastrophes."

The most argumentative and influential member of this party was Professor Buckland. He published in 1823 a work entitled *Reliquiæ diluvianæ; or, Observations on the Organic Remains contained in Caves, Fissures, and Diluvial Gravel, and on other Phenomena attesting the action of a Universal Deluge.* In this work Buckland showed that the majority of the Mammalian remains found in the caves and fissures belonged to the same genera and species as those which were found in the superficial gravels and clays. The latter he sub-divided into a lower or "diluvial" series and an upper or "alluvial" series comprising recent river and lake deposits. He emphasised the wide distribution of the diluvial deposits, and the fact that some of the animals interred in them belong to extinct species, others to existing species, and concluded that these deposits had been laid down by a universal deluge at no more remote date than a few thousand years ago.

Text-books and Handbooks of Geognosy and Geology.—The Text-books of Geology which appeared during the period between 1790 and 1820 showed an improvement on the speculative works of the preceding periods by their more matter-of-fact treatment of the subject. They may be taken as a standard of contemporary knowledge on geological subjects, and deserve special mention.

Most of the German text-books during this period were simply repetitions of Werner's teaching. As a rule mineralogy and geognosy were combined in the larger text-books, but in a few cases geognosy was published separately. Voigt's *Practical Knowledge of Mountains* (Weimar, 1792) was one of the best known, and it differed from Werner's teaching on several important points, such as the origin of basalt and the causes of volcanism. On this work Dietrich L. G. Karsten in great measure based his *Mineralogical Tables* (1800), which had a wide circulation.

The most complete and trustworthy text-book founded on Werner's teaching was that by Franz Ambros Reuss (Leipzig, 1801-6), in which six volumes are devoted to mineralogy and two to geognosy. The first volume of the geognosy or geology begins with a short introduction on the compass and domain of geognosy and the method of geognostic study. The first chapter treats the earth as a whole in its relation to other bodies of the universe, and states the most important facts of astronomy and mathematical geography. A second chapter is devoted to physiographical matters, the present constitution of the earth's surface and atmosphere, and the changes wrought on the earth's surface by existing natural agencies. The third chapter is occupied with the solid crust, describes the various kinds according to their composition and structure, their age and origin, and gives an account of the hypotheses concerning the origin and development of the earth. The rocks are sub-divided in five "formation suites," according to Werner. The fourth chapter contains a very full description of the regional masses of rock extending through mountain-systems or over wide areas. These are enumerated in the order of the "formation suites," and a careful account is given of their composition and texture, stratification or jointing, geological age, origin and occurrence, and the fossils or ores contained in them. A special chapter on metalliferous ores concludes this work, the contents of which show that the

Wernerian school already recognised most of the questions which are at present treated in text-books.

Considerations of the earth's physiography, dynamical geology, petrography, geogeny, and architecture or tectonic structure were fairly familiar ground at the time; the great difference is in the teaching of the chronological succession of the rock formations. Modern geology gives pre-eminence to the accurate determination of the age of the rocks, stratum by stratum, according to the contained fossils; Werner's disciples were satisfied with an approximate conception of the relative age of whole formations, and scarcely associated the study of historical succession of organised creatures with any geological interest or value.

In France, three distinguished pupils of Werner wrote text-books upon the basis of his teaching—Brochant de Villiers (1800), De Bonnard (1819), and De Voisins (1819). The *Treatise of Geognosy*, published by D'Aubisson de Voisins, won wide popularity on account of its clearness and the elegance in its mode of treatment. Like Reuss, D'Aubisson held closely to the methodical arrangement of the subject introduced by Werner in his lectures, so that the general arrangement of these two text-books is very similar; but the French author took his illustrative examples chiefly from French geology, Reuss from German districts. In common with most of Werner's disciples, D'Aubisson de Voisins made many blunders in respect of the Secondary formations. He united Alpine limestones (Tri.-Jur.-Cret.), the limestones of the Jura chain, the Magnesian limestones (Permian) and Liassic limestones of England and the German *Zechstein* (Permian) in one group—that of the Older Secondary limestones; and treated as Younger Secondary limestones, contemporaneous with German Muschelkalk, the Jurassic calcareous strata of France, the Forest Marble and Cornbrash, and Portland stone of England (Middle and Upper Jurassic), the Solenhofen lithographic stone (Upper Jurassic), and the fish-shales of Monte Bolca (Mid-Eocene).

An important deviation from Werner's teaching was made by D'Aubisson in his insertion of Tertiary formations between the Secondary deposits and diluvial clays and gravels. According to D'Aubisson, the Tertiary series included the deposits of the Paris basin (now grouped as Eocene and Oligocene), so clearly elucidated by Brongniart and Cuvier;

the Faluns of Touraine (Miocene); the formations studied by Omalius d'Halloy in N.E. France, Belgium, and near Mainz (cf. p. 106); the London Clay of England; the sandy, marly, and clayey strata of the Isle of Wight, which Webster had recognised as contemporaneous with the deposits of the Paris basin; the fossiliferous gypsiferous marls and lignite of Aix in Provence (Oligocene); the Oeningen shales and marls (Miocene); the fresh-water formations of Auvergne, Provence, Languedoc, Pyrenees, Spain, and Würtemberg (Miocene-Pliocene); the brown-coal and lignite in France, Germany, and England.

The fossils occurring in these strata are also enumerated by D'Aubisson, but there is no attempt to determine a series of palæontological horizons, or even the relative age of the Tertiary deposits present in the various localities.

The excellent work of D'Aubisson de Voisins is the only one which merits the name of a text-book for teaching purposes.

Robert Jameson, who tried to disseminate Werner's doctrines in Great Britain, met with less success in his *Elements of Geognosy* (1808). The works of Hutton, Playfair, and William Smith wielded a powerful influence, and were guiding British geologists with firm steps towards a right understanding of igneous rocks and the palæontological succession of organic types.

An *Introduction to Geology*, written by Robert Bakewell in 1813, ran rapidly through a number of editions. Although following Werner in the general treatment of the subject, Bakewell took up a neutral attitude on most contested points, and showed a just appreciation of Hutton's views. His work presented a clear statement of the leading geological features of England, and included many of his own observations. Strange to say, Bakewell was no supporter of the determination of the age of rocks by the comparison of fossils. William Smith's investigations were not incorporated, and even in the fifth edition, published in 1838, the name of William Smith was never mentioned.

Scipio Breislak's somewhat speculative and diffuse *Introduzione alla Geologia* (1811) was rapidly translated into both the French and German languages, and had a fairly wide circulation. It represented a quite different standpoint from the text-books written by disciples of Werner. Whereas the

latter made it their chief desire to keep strictly to an account of known geological facts, Breislak throughout his work concerned himself mainly about the causes of geological phenomena. And the reactionary influence of Breislak's work proved so far healthful; but chemistry and physics were still too little advanced to permit of an adequate solution of most geological phenomena, and ingenious as Breislak's conceptions were, they were seldom correct, and led him often far astray. The best part of the work is the third volume, in which Breislak gives a good account of volcanic phenomena and volcanic rocks in Italy, and contributes a number of valuable observations on gaseous explosions, volcanic ejecta, and on lava and basalt.

Fourth Period—Newer Development of Geology and Palæontology.

The leaders of thought, whose activities towards the close of the eighteenth, and in the first twenty years of the nineteenth century, won for geology an acknowledged place as a scientific study, were almost all of them men of independent means. Only a limited number of the founders of geology and palæontology belonged to teaching bodies. The universities were unwilling to countenance young and indefinite sciences, and only tardily incorporated them in their academical curricula. But when one after another of the universities recognised geology and palæontology, the result could only be beneficial, and that rapid progress began which has continued uninterruptedly to the present day.

Collections of rocks and fossils were started in all university towns, and laboratories and institutes were founded and equipped in order that beginners in the study might have every assistance in their work, and that the more advanced students might be given every inducement to follow out selected lines of original research. The number of students steadily increased, the output of special papers became more voluminous, and every year the subject-matter of the collegiate course became more comprehensive.

At first the universities, more especially in Germany, where Werner's system was the supreme precedent, placed the newer branches of geology and palæontology under the care of the

mineralogical professors, but, soon, specialisation was felt to be necessary, and professorships began to be founded for geology and palæontology as a distinct scientific study.

The encouragement given by the strict academical system of preparation and research, and the higher standard in the demand for accurate detail, had the effect of diminishing the influence of private individuals. Leopold von Buch, Charles Lyell, De la Beche, and Murchison are among the few leaders of modern geology who worked independently.

With specialisation in geology and palæontology, the springtime of the science was over. The period was past when a man could mentally survey the whole field of petrographical knowledge, when great discoveries lay, so to speak, by the roadside, and only required to be observed. Instead of hasty, widely extended observations and broad generalisations, there began now the less brilliant, but more lasting, investigation of details. The telescope of a geological traveller surveying the rocks from afar was exchanged more and more for the microscope of a specially trained academician. The rapid advances made by modern geology are due to concentrated endeavour in the solution of problems of a definite and limited character, and the universities and academies have sedulously fostered the accomplishment of such work.

Among German universities, Berlin has always held a distinguished place. Gustav Rose, Ehrenberg, and Beyrich[1] were some of the famous teachers in Berlin University. For nearly sixty years Beyrich exerted a strong influence on the younger generations. Although without any great oratorical gifts, Beyrich fascinated his hearers by the carefully considered subject-matter of his lectures and the breadth of his knowledge, while in his practical teaching in the field he provided a model of accuracy and completeness. Not a few of the greatest

[1] Heinrich Ernst Beyrich, born 1815 in Berlin, entered the Berlin University at the age of sixteen, and presented his thesis in 1837. Soon afterwards he was appointed an assistant in the mineralogical museum, and in 1857 was made director of the palæontological collection. As a teacher he was first a *privat docent* (a university tutor), then an extra-Ordinary professor, and in 1865 became full Professor of Geology and Palæontology in the University and in the Mining Academy. In 1848 the German Geological Society was founded, and Beyrich was one of its promoters. In 1873, when the Prussian Geological Survey was instituted, Beyrich was appointed co-director with Hauchecorne. He died in Berlin on 9th July 1896.

teachers in Germany—Von Richthofen, Von Koenen, Dames, Kayser, Eck, Credner, and others—were pupils of Beyrich.

Beyrich was also one of the most active promoters of the Geological Society of Germany. Since the Society was founded in 1848, it has combined and centralised almost all the geological activity throughout Germany. The seat of the Society is in Berlin, but the annual congresses meet each year in a different German town.

Bonn rivalled Berlin for a long time as a leading centre of geological interests. A brilliant phalanx of geologists—Roemer, Goldfuss, Bischof, Vom Rath, and others—made Bonn a much favoured university in the middle of the nineteenth century. Ferdinand Roemer's *Description of the Schist-Mountains of the Rhine* and Goldfuss's *Petrefacta Germaniæ* are monumental scientific works; G. Bischof's famous *Text-book of Chemical and Physical Geology* opened a new and fascinating domain of scientific research to young minds; and Bonn was the centre from which a reformation in petrographical methods spread over Germany.

The pioneer labours of Sorby in his microscopic examination of rock structures were first appreciated in all their significance by Ferdinand Zirkel, who at that time taught in Bonn. Zirkel followed along Sorby's lines with such admirable skill that his researches became known in every land and gave a powerful impulse to the study of petrology. In Germany, work in this direction has been worthily continued, and Rosenbusch and his school have applied microscopic methods more particularly to the study of crystallography.

Leipzig University was fortunate in having for thirty years (1842-73) C. Fr. Naumann as Professor of Mineralogy and Geology. Naumann's most important work is his *Text-book of Geognosy*, which is acknowledged to be the most complete and thorough compendium of this science, and for many decades has served as a standard book for German students. The remarkable success of Naumann as a teacher attracted a large number of mineralogical students to Leipzig, and the tradition has been well sustained by Naumann's successors, Hermann Credner and Ferdinand Zirkel.

Heidelberg University, where Rosenbusch now teaches, has always enjoyed a high reputation for mineralogy and geology. Carl von Leonhard, the editor of the Mineralogical *Taschenbuch*, and the founder of the *Neues Jahrbuch für Mineralogie*,

Geologie, und Palæontologie, was professor at Heidelberg for a long period of years; and associated with him was Heinrich Georg Bronn, the zoologist and palæontologist, whose *Lethæa geognostica* is still one of the main pillars of historical geology and palæontology.

Munich University was the first in Germany to institute a full or "Ordinary" Professorship for Geology and Palæontology. Schafhäutl, appointed professor in 1843, occupied himself chiefly with the investigation of the Bavarian Alps, which were then unknown geologically. He was joined in this work, in 1851, by Wilhelm Gümbel, who afterwards became director of the Bavarian Survey. During forty years Gümbel worked indefatigably in the field and as an administrator, and no single individual has done more for his country's cartography and stratigraphy than he has done for Bavaria. His works on Alpine geology are known to all students of complicated mountain structure, and are thoroughly scientific in tone and treatment. It is clear that the geographical position of Munich, at the base of the Alps, singles it out among German university towns as being particularly advantageous for the study of mountain structure. In 1866, Karl von Zittel succeeded Albert Oppel as Professor of Geology and Palæontology, and since that time the fossil collections have been vastly extended. A special collection has been arranged for tutorial purposes, and the large state collection is considered a model of methodical display.

In Tübingen, Friedrich Quenstedt taught for more than half a century (1837-89). One of the most versatile and original of German geologists and a born teacher, Quenstedt not only attracted numerous students, but also aroused an interest for geology and palæontology amongst the agricultural classes of Franconia, Swabia, and Würtemberg. What William Smith and Buckland did in determining the palæontological horizons of the Jurassic series in England was accomplished by Quenstedt in Lower Bavaria. At the present day the common people, in the districts where his influence extended, are many of them enthusiastic fossil collectors, and arrange their miniature collections with an astonishing accuracy. One of the best-known disciples of Quenstedt was Oscar Fraas, who created in Stuttgart a local fossil collection worthy of the best traditions of his teacher.

The above-mentioned are only a few of the German univer-

sities; there are many of the smaller universities and polytechnic schools whose professors have won fame both in scientific research and as teachers.

In Austria and in Switzerland the majority of the more distinguished geologists and palæontologists since the year 1820 have belonged to academic circles. The famous names of Eduard Suess, Ferdinand von Hochstetter, and Melchior Neumayr are associated with Vienna. Bernhard Studer in Bern and Arnold Escher von der Linth in Zürich must be regarded as founders of geological science, while Louis Agassiz and Eduard Desor in Neuchâtel and Alphonse Favre in Geneva are names of world-wide fame.

In comparison with Germany the teaching element is less equally distributed in France and England. The huge metropolis in each of these countries has always been the leading centre of mental activities, and has dwarfed the minor centres throughout the country. More especially is this the case in France, where Paris has been the centre of all geological and palæontological efforts since the days of Buffon, Cuvier, Lamarck, and Brongniart. The great French representatives of these studies are connected with the Botanical Gardens, the Sorbonne, or the School of Mines. In the provincial towns geological teaching is given partly by University professors, partly by private teachers, and partly by mining engineers. In 1830, Constant Prévost, together with Ami Boué, Deshayes, and Desnoyers, founded the Geological Society of France, which has become, by means of its publications and its Congresses, the most influential French organisation in geology and palæontology.

In Great Britain, a no less important position is held by the Geological Society of London, founded in 1807. Its publications present a true mirror of the whole historical development of geology and palæontology in Great Britain during the last century, and the list of the Presidents of this Society, as well as of the Wollaston medallists, includes the most deserving geologists of the country. The old universities, Oxford, Cambridge, Edinburgh, Aberdeen, and Dublin, which in the heroic period of geology gave some of the great founders to science, still maintain their reputation in geology under able professors, and some younger colleges, such as Birmingham, now rival the older schools as seats of scientific learning. In Edinburgh, a number of enthusiastic adherents of Hutton founded the

Scottish Geological Society in 1834, which took the place of Jameson's "Wernerian Society."

Scandinavia early distinguished itself in geological and mineralogical studies: Keilhau and Kjerulf in Norway, Nordenskiöld, Torell, Lindström, Nathorst, and other Swedish investigators, and Forchhammer and Steenstrup in Denmark, contributed much to the rapid progress in the earlier decades of the nineteenth century. Italy suffered in its scientific development during the prolonged and frequent political disturbances, but much has been done in the latter half of the nineteenth century. Russia has, of late, been most energetic and generous in its encouragement of geological and palæontological researches.

The third decade of the nineteenth century saw the beginning of active geological research in North America; and at the present day the United States and Canada are not behind any European land in their scientific attainments and societies.

In proportion as geology continued to expand its scientific interests, its bearing upon many important technical questions began to be realised. It was represented to statesmen that geology could give valuable indications respecting mining and industrial prospects, road and railway construction, agriculture, and forestry. A desire crept in among public bodies for geological maps and reports of whole countries, and not only of local areas specially interesting to science. Practical England made the beginning. In 1835, under the direction of De la Beche, the governmental department of the Geological Survey of the United Kingdom was established, and special branches were formed for Scotland and Ireland, and afterwards also for the extra-European British Colonies.

Almost simultaneously, Dufrenoy and Élie de Beaumont were commissioned in France to prepare a general geological map of that country, and after its completion in 1841, the State arranged for a more detailed survey. Michel Lévy now directs the French Survey, which is carried on chiefly by mining engineers. Other States gradually followed the example of Great Britain and France, and every cultured nation now has its Survey Department for the investigation of the constitution of the ground and the mineral products within its territories.

The establishment of State Surveys naturally removed some of the work that had previously fallen to the share of University professors and tutors; in not a few countries, however, the

professors have to combine both University and Survey duties. The Survey Departments have always preserved a strictly scientific character, and while fulfilling to the utmost the practical and commercial purposes for which they were in the first instance called into existence, their systematic treatment of vast land areas has furnished the pure science of geology with a wealth of observations of inestimable value for its more abstruse problems.

The progress of geological cartography brought the results of one State Survey into touch with those of its neighbours. So far as geology is concerned, the present boundaries between adjacent countries are merely of accidental character, even the present configuration of a land surface is merely an episode in the historical cycle of events; in the previous epoch lands now separated may have been the common floor of a bygone sea. The nature of geological and palæontological studies necessitates a constant interchange of knowledge between the different countries of the globe. The geologists of the Paris basin, for example, must know the results of the geologists of the London basin, maps ought to agree, faunas ought to be compared; and these considerations led to the institution of International Geological Congresses, where geologists from all countries might discuss the problems of common interest to the science. Some of the greatest men of our time, in attending these Congresses, have expressed their conviction that the intellectual fellowship of interest renders them a humble means towards a very great end, whereby nations, by better acquaintance with each other, may become more firmly welded in political friendship.

Geology and palæontology give great promise for the twentieth century In another hundred years the whole surface of the earth will perhaps be so well known, that works on comparative topographical geology will be fully accomplished along the lines which Eduard Suess has so ably initiated in his *Antlitz der Erde*. If at the same time the structural and physical problems of the solid earth-crust continue to be accurately investigated in all parts of the earth, it may be possible to determine the actual physical sequence of events in the origin and development of our planet.

Again, the palæontologist notes with interest how the study of past forms of life is brought every year into closer relation with biological researches, and how, as faunas and floras from

foreign parts become better known, the gaps in the palæontological record are shown to be less insurmountable than was at first supposed. On the other hand, it may be that an enriched knowledge of extinct organic remains and their precise distribution in the various layers of the stratigraphical succession throughout the globe, will enable biologists to draw more definite conclusions regarding the first derivation, and the history of the descent and development of the manifold forms of organic life that have peopled the earth.

CHAPTER I.

COSMICAL GEOLOGY.

Cosmogony.—It does not come within the domain of geology to investigate the origin of the universe and of solar and planetary systems. Yet such investigations are so closely associated with the origin and earliest history of the earth, that the results attained by astronomical researches have at all times exerted an influence upon the views of geologists. Visionary speculations about the beginnings of the universe and the earth were much in favour during the eighteenth century, and almost every geological work of a general character had an astronomical introduction. In the early part of the nineteenth century speculation gave place before the great discoveries that were being made in astronomical physics. The explanation given by Kant and Laplace of the origin of the universe and the solar system found general acceptance, and further speculations on cosmogony and geogeny were thought to be either unnecessary for the immediate purposes of geology as a science, or were discouraged on account of their tendency to be wholly theoretical. Thus there followed a long period during which the cosmical aspects of geology made little advance.

In the year 1871, at Brunswick, Helmholtz gave expression in a popular lecture to the current conception of the earth's origin, based upon the principles of Kant and Laplace: "Our solar system was originally a chaotic nebular ball; at the beginning, when the nebular mass extended as far as the path of the outermost planets, many millions of cubic miles could contain scarcely one gramme of mass. At the time when this nebula became separated from the nebular masses of the neighbouring fixed stars, it possessed a slow movement of rotation. The natural attraction of its parts caused the nebula to condense, and in proportion as it condensed, rotation must

have become more rapid, and have tended to make it discoid. From time to time masses became separated at the circumference of this disc under the influence of the increasing centrifugal force. These masses again assumed the form of rotating nebular balls, and either simply condensed as planets, or during condensation also gave off in turn peripheral masses which became satellites or remained, in the case of Saturn, as a connected ring. In another case, the mass which separated at the periphery of the main nebula broke up into a number of nebular fragments, and gave origin to the swarm of small planets between Mars and Jupiter. It has been determined more recently that this process of condensation of loosely composed bodies is still continuing, although in less degree."

A new field of research was opened for astronomy in 1859, when the spectroscope was discovered by Kirchhoff and Bunsen. It was then rendered possible to learn something definite about the materials composing the stars and the sun. By the use of the spectroscope it has been ascertained that all matter has essentially the same constitution throughout the universe, the same substances taking part in the composition of the earth, the sun, the fixed stars, and the planetary nebula.

The mechanical theory of heat, together with the principle of conservation of energy founded by Robert Mayer and by Helmholtz, afforded an exact explanation of the high temperature of self-luminous cosmical bodies, since an enormous supply of heat must be absorbed during the processes of condensation of gases and differentiation of atoms. According to Helmholtz, the supply of heat which the sun has accumulated during its condensation is sufficient, if calculated on the basis of its present expenditure of heat, to have extended over an interval of time in the past equivalent to twenty-two million years. And as the sun is still in process of condensation, it may yet continue for many millions of years to radiate and to impart its animating sunshine to the planets.

Thus, in respect of the unity of matter and the temperature of solar and planetary bodies, the nebular theory of Kant and Laplace was confirmed by spectroscopical research and by the mechanical theory of heat. But it encountered serious difficulty when astronomers discovered that the rotation of the satellites of Uranus and Neptune takes place from east to west,

a fact of which neither Kant nor Laplace had been aware. Uniformity in the rotation of all the bodies in the solar system is the fundamental conception in the theory of Laplace; yet this conception was directly contradicted by the discovery that the satellites of the two planets farthest from the sun rotated in a direction opposite to the direction of rotation of all other known bodies in the solar system. Other weak points in the theory of Laplace rendered it open to criticism. Kant had supposed that the atoms of primitive matter originally possessed the property of mutual attraction and repulsion, and a whirling motion, and that they gradually attained a uniform rotatory movement, while Laplace, on the other hand, had assumed the rotatory movement as inherent in matter; but neither Kant nor Laplace had tried to offer a satisfactory explanation of the phenomena of rotation. Moreover, these physicists had not attempted to explain the incandescent state of certain celestial bodies; Laplace had merely assumed that matter was provided with an indefinite supply of heat, without offering any scientific hypothesis for the origin of heat. Again, a further contradiction was presented to the theory of Kant and Laplace by the approach of comets from regions of considerable space beyond the solar system.

Several attempts were made to replace the theory of Kant and Laplace by a more satisfactory one. One of these was Mädler's hypothesis in 1846, which postulated a common centre for the whole universe of fixed stars, but not a central sun whose superiority of mass controlled the movements of other bodies. The movement of fixed stars was said to be under the direction of an ideal centre of gravity. This assumption contradicted the idea of the successive formation of rings and the separation of masses of matter from a central body. According to Mädler, the ring-theory of Laplace could not possibly be held to apply to the numerous double stars.

The French astronomer, Faye, brings forward some remarkable conceptions in his recent work, *Sur l'Origine du Monde*, published in 1896. Faye does not accept the existence of a central mass either in the case of the heaven of fixed stars, or in our solar system. He supposes that originally a part of the universal matter had a slow, whirling movement, and that neighbouring masses of matter developed a movement in a similar direction as a consequence of the action of gravitation and mutual attraction. Thus the myriad of heavenly

bodies took origin, and during condensation developed heat and light. If a star has planets associated with it, as in the case of our sun, the origin of these planets is, according to Faye, to be traced to the original slow, whirling movement of some part of universal matter.

Considerable masses of primitive matter unite in the form of flattened rings, originally surrounding an empty centre of gravitation. The rings are gradually disrupted into a number of rotating masses, whirling with the same direction as the parent ring, greater masses attract smaller, absorb them, and finally a spherical body is formed. The planets originate in this way, those planets forming first whose component rings are relatively nearer the centre of gravitation. Meantime, finely divided fragments of matter meet in the centre of such a system, and begin to give origin to a sun. It is impossible here to enter further into these new conceptions of cosmogony so recently advanced by Faye.

The Sun.—The first information about the physical constitution of the sun was obtained by the use of the telescope.

David Fabricius, the son of a pastor in East Frisia, discovered in the year 1610 movable spots on the sun, and his observations were confirmed a few months later by the Bavarian Jesuit Scheiner, by the Englishman Harriot, and the Italian Galilei. Fabricius explained the sun-spots as slaggy separations from the inner incandescent nucleus of the sun; Scheiner regarded them as foreign masses circulating round the sun; Galilei thought them clouds occurring in the sun's atmosphere.

From the variability in the position of the sun-spots Scheiner drew for the first time the important conclusion that the sun rotated.

The significance of the sun-spots is still a matter of discussion among astronomers. Herschel suggested in the early years of last century that the sun-spots were cavities in the glowing atmosphere, through which the dark body of the sun was visible. This suggestion found much acceptance, until it was disproved by the spectroscopical researches of Kirchhoff.

Kirchhoff in 1861 showed that the white-hot sun's mass was surrounded by a photosphere in which numerous substances familiar to us in the earth's constitution were present in a

state of vapour. Kirchhoff then suggested that clouds formed in the white-hot photosphere, and that these clouds became darker as they cooled, thus giving origin to the appearance of sun-spots.

Zöllner contested this hypothesis on the ground of the relatively small variation in the shape of the spots, and agreed with the explanation given by Fabricius. Reye and Faye regarded the sun-spots as a result of cyclones in the lower region of the sun's atmosphere. There can be no doubt that storm movements take place at the surface of the sun. This was made evident when Sir Norman Lockyer in 1869, and in his later work on *Solar Physics* (1873), demonstrated the presence of a mantle of glowing vapour from which there projected gigantic torch-like protuberances subject to violent movement. Lockyer called the outer mantle of the sun "chromosphere" on account of its red colour.

All the modern theories about the constitution of the sun agree in assuming that it must have received an immeasurably great supply of heat during its condensation, and that already a considerable quantity has been lost by radiation. Nevertheless, the sun is still in a white-hot condition, and replaces the loss of heat by continued condensation and by absorption of matter attracted from sidereal space. The spectroscopical researches of Kirchhoff, Secchi, Zöllner, Lockyer, Young, and others, have demonstrated that more than half of the terrestrial elements are present in the composition of the sun.

In the present position of astronomical research there is no precise means of determining the temperature of the sun, although its size and density are well known. The sun is more than a hundred times larger than the earth, but has only a quarter of the earth's density. It follows from the continuity of the sun's spectrum that the sun's nucleus is incandescent, but it is difficult to decide whether the material is in a liquid state, as Kirchhoff and Zöllner suppose, or whether Secchi and Faye may be correct in supposing the nucleus to be for the most part gaseous, including some denser portions in a state of stormy movement.

The Fixed Stars and Planets.—While the sun represents a celestial body not yet fully consolidated, although in an advanced stage of condensation, the nebulæ, fixed stars, and planets give indication of the phases of development through

which a celestial body passes before and after its consolidation.

The differences in the colour and brightness of the fixed stars suggested to the early astrologists that the stars differed in their individual constitution. The catalogue of the Ptolemaic Stellar Chart classifies the stars in six groups according to their brilliancy. The attempt was frequently made—by Sir William Herschel among others—to erect a more precise system upon the basis of the intensity of the light radiated from the different stars, but no satisfactory result was obtained. The grouping of stars according to their colour met with more success. The early astrologists distinguished white, yellow, and red stars; in 1686 Mariotte observed blue stars for the first time; and later, in 1782, Herschel observed double stars displaying different colours. By means of the spectroscope recent researches have arrived at an explanation of the different brilliancy and colour of the fixed stars.

The sun and all fixed stars have a continuous spectrum that is interrupted by the dark lines of the vaporous substances in the photosphere; the Fraunhofer lines are absent in the spectra of planets, or bodies which have only reflected light. Angelo Secchi in his work on "the sun," in 1872, distinguished four groups according to the spectroscopical character of the stars: 1, white and blue; 2, yellow; 3, orange-coloured and red; 4, blood-red.

Secchi, Vogel, and Scheiner (1890) regard the differently coloured stars as bodies representing different phases in the cooling of nebulous masses. According to their investigations, the white and blue stars are the brightest and hottest; their temperature is so high that the gases and metallic vapours in their photosphere only exert a very slight absorptive power, and the spectra are consequently either quite simple or show extreme faint lines. The vast concourse of yellow stars are in the farthest phase of condensation, which is represented by the sun or central star of our system; their spectra exhibit numerous and powerful dark lines, indicating the presence of several of the metals in addition to gases and metallic vapours. The spectra of the red stars display broad dark streaks indicative of metallic compounds, and it is inferred that the temperature in those stars must be sufficiently reduced to allow the metallic vapours in the atmosphere to enter into various chemical combinations. The spectra of some of the

nebulæ were examined in 1869 by Huggins and Miller, and the results indicated the presence of vapour, of water, and in addition an element which, unknown in the earth, has been determined in the sun's spectrum and termed "helium."

Next to the red stars may be grouped the so-called new and variable stars, sometimes brilliantly luminous, sometimes growing rapidly obscure or quite vanishing from observation. These probably represent bodies in a far-advanced stage of cooling, but which, owing to collision with other bodies in the universe, or to internal changes, temporarily ignite, emit eruptions of glowing gases, and perhaps in some cases also eruptions of molten rock-masses.

By mathematical calculations astronomers have determined that in addition to luminous stars, there must be completely cooled dark bodies in the vault of heaven. Thus the sidereal world exhibits all phases from the nebulous, incandescent, gaseous, and vaporous states to the cooled and solid condition.

The further history of a cooled celestial body surrounded by a firm crust is displayed in the various conditions of the planets and satellites of our solar system, and these have therefore a closer interest for geology. The planets move round the sun in slightly elliptical paths at definite distances from it. Of the six planets that were known in early astrology, Mercury is nearest the sun in position, and has itself a diameter of 648 miles; Venus (diam. 1,613 miles) follows Mercury, then the Earth (diam. 1,719 miles), then Mars (diam. 909 miles), Jupiter (diam. 19,000 miles), and Saturn (diam. 16,675 miles). Herschel in 1780 discovered on the farther side of Saturn the planet Uranus with a diameter of about 8000 miles, and Leverrier in 1846 discovered, by mathematical calculation, the outermost planet, Neptune, with four and a half times the diameter of the earth.

The paths of Mars and Jupiter are separated by a much greater distance from one another than the paths of the inner planets. Piazzi in 1801 discovered the small planet Ceres in this gap, and later there have been discovered more than 400 small planetoids or asteroids, a number which is continually being added to by new researches. The Earth has one satellite, Mars two, Jupiter five, Uranus four, Saturn eight, Neptune one. Saturn is also further distinguished by the possession of a broad ring freely suspended over the equator and separated into three parts.

In comparison with the Earth, the relative density of the planets is as follows:—

Sun	0.25	Jupiter	0.24
Mercury	1.12	Saturn	0.13
Venus	1.03	Uranus	0.17
Earth	1.00	Neptune	0.16
Mars	0 70		

The inner planets are therefore considerably heavier and more firmly consolidated than the outer.

Great advances have been made in our knowledge of the physical constitution of the planets by means of improved telescopic methods and the construction of the modern large telescope. Mars has always been an interesting object of astronomical observation. As early as 1659, Huygens observed white spots at both poles, and the elder Herschel in 1781 was able to draw a sketch of the surface of Mars, which was afterwards improved by Hieronymus Schröter on the basis of researches conducted between 1786 and 1803. Beer and Mädler distinguished pale, white, and yellowish-red spots from dark greenish-blue spots, and regarded the former as land masses, the latter as seas. Maps of Mars were published by several other astronomers. The Milan astronomer, Schiaparelli, published in 1878 a work which added much to our knowledge of Mars. The dark streaks crossing the light spots in straight or in bent lines, opening into the dark, iron-grey seas, are regarded by Schiaparelli as canals, and are mapped with hitherto unsurpassed precision, while he confirms the observation that mountain-chains and solitary mountains are quite absent.

The telescopic examination of the rest of the planets has so far brought less satisfactory results. The small planet Venus, next in position to the Earth, seems to be surrounded by a dense, cloudy atmosphere, which obscures the view of the actual surface of the planet; at the same time recent observations have demonstrated round or elliptical spots of light colour (perhaps continents dimly visible through the atmosphere), and these are separated from one another by dark ribbon-like streaks.

Keeler in 1889, by the use of the famous refractor of the Lick Observatory, obtained the first information about the constitution of Jupiter. With this instrument two reddish

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bands are visible at both sides of the equator, and a number of smaller streaks run parallel to them. An elliptical red spot can also be seen. From these observations it would appear that this planet is encircled by a mantle of cloud or by floating layers of vapour, through which the still incandescent nucleus shows itself as a red spot. Saturn displays a surface similar to that of Jupiter; its remarkable ring was explained by Kant as a vaporous mass composed of infinitely fine particles. The two outermost planets are too remote from the Earth to permit of detailed telescopic examination.

As regards the spectra of the planets, Fraunhofer had determined their agreement with the sun's spectrum, and in more recent years the spectroscope has shown that for the most part the planets only reflect the sun's rays.

If one may venture to draw conclusions from these observations, Mars with its thin atmosphere may probably be regarded as the planet most akin to the Earth. Mars, and possibly Venus, with its thick cloud-mantle, are the only planets upon which living creatures could be supposed to exist. Life must be impossible on Mercury on account of its proximity to the sun; Jupiter and Saturn radiate light of their own to a certain degree, and are probably still in an incandescent state. The spectra of Uranus and Neptune would seem to indicate a condition of incomplete consolidation, and the low density of these planets is an additional fact in favour of this hypothesis.

The Moon.—The moon is the heavenly body which has been examined by astronomers in greatest detail. This has been rendered possible by its relatively small distance from the earth, the absence of water or clouds, as well as by the absence or very slight development of an atmosphere on the side of the moon which is exposed to us. Although classical literature contains scattered observations regarding the moon's surface, the cartography of the moon was not attempted until the telescope came into use. Then Galilei and other astronomers of the seventeenth century made sketches of the moon's surface. In the middle of the eighteenth century Professor Tobias Mayer projected a topographical map of the moon on the basis of measurements, the precision of which far surpassed previous attempts. In the earlier part of this century several astronomers published maps and reliefs of the

moon on various scales. The largest chart was published on 1878 by Julius Schmidt, and with the work of this great astronomer the older methods of investigation may be said to have reached their highest point.

A new era began with the application of photography to the representation of moon landscapes. Warren de la Rue in London, Draper and Rutherford in America, obtained photographs of remarkable beauty. But the earlier results of photography were far exceeded when the astronomers of the Lick Observatory in California made use of their giant lens. The large number of landscapes obtained by this means are now being compiled by Weinek in Prague, and a large Atlas of the moon is being prepared. The English astronomers, Nasmyth, Carpenter, Proctor, and Neison have also contributed very greatly within the last twenty years to the knowledge of the constitution of the moon.

From all these observations it has been proved that the moon, unlike Mars, has no seas and canals, in short no water, but possesses a wonderful array of mountains. With the naked eye, darker-looking areas can be distinguished on the moon's surface. From these rise numerous conical mountains, truncated at the top and with deep craters, ring-shaped mountain-ramparts, and magnificent, deeply-fissured mountain-massives, whose summits are as high as 25,000 feet above the surrounding areas. In addition to these mountain-craters and rings which indicate a volcanic origin, certain rents have been discovered by Schröter in the plains, sometimes penetrating the volcanic cones, and therefore clearly of subsequent origin. A special geological interest attaches also to the presence of light streaks radiating from the craters. Whilst the rents might readily find an explanation as fractures due to contraction, the radially-arranged light-streaks present a difficult question, and some authorities incline to regard them as streams of lava, others again as evidences of sulphurous springs.

The surface conformation of the moon is by no means constant in character. Schmidt in 1866 confirmed the disappearance of an earlier crater, while Klein and Neison in 1877 saw the formation of a new crater.

The American geologist Gilbert has contested the opinion generally accepted at the present day, that the craters and ring-shaped ramparts in the moon are volcanic in their origin.

Gilbert regards them as impressions made upon the moon by the collision of gigantic meteorites.

More recently, Schmick, George Darwin, and Ebert have endeavoured to trace the surface conformation of the moon to the undulations of a magma originally in hot, flowing condition. Suess has also elucidated the present surface of the moon upon the basis of volcanic occurrences; he compares lunar surface forms with the internal seething and buoyancy of melted masses of mineral or metallic material, and in this way sets forth a genetic table of the various lunar forms.

Meteorites and Falling Stars.—Reports of stones and masses of iron fallen from the heavens may be traced into remote periods of antiquity. The oldest known account is a report in China in the year 644 B.C. The Phœnicians, Egyptians, and Greeks used to preserve meteor-stones in temples, and to do honour to them as visible signs sent them by their gods.

Pliny has recounted how at Ægos Potamos, in Thracia, in the year 476 B.C., a mass of iron fell, "as large as a chariot," and was afterwards said by Anaxagoras to have been a fragment broken from the sun.

Avicenna mentions reports of fallen stones from Egypt and Persia. There seems little doubt, according to Consul von Laurin (1845), that the sacred stone in the Kaaba of Mecca is a meteorite. Various accounts of meteorites in Germany date from the early Middle Ages. A fall of meteorites took place at Ensisheim, in Alsace, on the 7th November 1492, and the account describes how a hot mass of stone, 127 kilogrammes in weight, fell into a field of wheat, accompanied by violent noises and the appearance of fire. Emperor Maximilian I. commanded that the stone should be preserved in the Church of Ensisheim. During the French Revolution the stone was taken to Colmar, and was then considerably cut down, so that now the remnant returned to the Ensisheim church only weighs about 40 kilogrammes.

A full report was also given of a shower of meteorites that occurred at Crema, in Italy, in 1510 or 1511. Although the number of reports of fallen stones increased very greatly in the seventeenth and eighteenth centuries, the scientific opinion of that time made merry over the credulity of the people who imagined the stones fell from the heavens.

Stütz, for example, who was a director of the Natural History

Collections in Vienna, said in 1751 that such stones had been erroneously regarded as rarities, and should be thown away! Fortunately this advice was not followed.

A Commission of French observers was entrusted with the investigation of a meteorite that fell at Lucé, in the province of Maine, in September 1768. The Commission drew up a detailed description of the mineral constitution of the stone, but stated it to be a physical impossibility that the stone could have fallen from the heavens.

The great Wittenberg physicist, Chladni, at last demonstrated the correctness of the popular idea regarding meteorites. He published in 1794 a classical work, *On the Origin of the mass of iron found by Pallas in Siberia, and the explanation of the physical appearances associated with the falling of this and other similar masses.* Chladni regards meteorites as fragments of cosmic bodies, which, while travelling through space with enormous rapidity, come into the neighbourhood of the earth and are attracted by it; they become heated by the friction of the atmosphere, melt superficially, and finally break up owing to the development of gases and elastic fluid materials. This is, in its essential features, the view that is at present held by most authorities.

Since the appearance of Chladni's work a great number of meteors have been reported, and a careful register of meteorites has been drawn up in the writings of several astronomers, while the best specimens have been placed in museums.

Although it might have been supposed that the full details and the precise scientific basis of Chladni's work would convince all investigators, this was far from being the case. Some still held the opinion that meteorites were of telluric origin, while Laplace and Berzelius regarded them as volcanic refuse from the moon. Tschermak thought them fragments from the volcanic eruptions taking place on the earth and on other cosmic bodies.

The Englishman Howard was the first to investigate the chemical composition of meteorites. He showed that all meteorites have a similar composition, and chiefly consist of silicic acid, magnesia, iron, nickel, and sulphuret of iron. The investigations of other chemists have confirmed Howard's results, and demonstrated the presence in smaller quantity of a number of additional elements. In comparison with terrestrial rock-material the number of ingredients is very

limited. Quartz, orthoclase, felspar, mica, hornblende, leucite, nepheline, garnet, and all hydrous silicates are absent, whereas very few of the minerals which have been recognised in meteorites are not known in the earth.

In the latter part of this century, thin sections of meteorites have been examined microscopically, and it has been shown that there is more structural difference between the terrestrial and meteoric rock than had been supposed from macroscopic examination. Meteorites are in many cases composed of radiating spherical bodies (chondrites) or irregular fragments; the rent character, the paucity of steam vesicles, and the absence of liquid contents give to microscopic slides of meteorites an unfamiliar appearance, and seem to indicate that they have taken origin independently of the action of water and vapour.

The classification of meteorites is a very vexed question, some authorities placing more value upon chemical and mineralogical distinctions, and others upon structural distinctions. Partsch in 1843 distinguished two main groups—stone meteorites and iron meteorites. Reichenbach rejected these groups as too broad, and classified meteorites in nine groups according to physical character, especially the colour and the mineral contents. Gustav Rose, who was Professor of Mineralogy in Berlin University, supported the earlier classification of Partsch, but arranged sub-groups upon a mineralogical basis. Daubrée, the French physicist, in 1867 distinguished meteorites containing iron or Siderites, from Asiderites or meteorites without iron, and sub-divided these again. Meunier accepted Daubrée's main groups, but erected a very large number of sub-groups. In England, the meteorites represented in the Collection of the British Museum were arranged in three groups according to Story-Maskelyne's classification in 1870-71: (1) Siderites (meteoric iron), (2) Siderolites (meteoric stones containing iron), and (3) Aerolites (meteoric stones without iron).

The study of meteorites, as Daubrée remarks, touches several of the fundamental questions in the history of the universe. They are the only specimens of non-terrestrial or cosmic bodies which we have an opportunity of investigating, and which can yield an insight into the constitution of those masses occupying the vault of heaven. The number of accredited falls of meteorites does not exceed a thousand, and

as a rule the fragments which fall are small, sometimes merely a dust-shower. The fact that many meteorites consist wholly of metallic iron (with nickel), while others contain a large intermixture of iron grains in a matrix of silicates, indicates that iron plays a greater part in the composition of the planetoids than in that of terrestrial rock-material, in which it almost always occurs in combination with oxygen or sulphur.

In the year 1870 Nordenskiöld discovered on the coast of the Greenland island Disko, near Ovisak, gigantic blocks of solid nickelic iron weighing several thousand kilogrammes. These were at first thought to be meteoritic, until Steenstrup and Daubrée showed that the basaltic rocks of Disko contain greater and smaller inclusions of iron, which are identical with the great blocks in every particular. It would thus seem that considerable masses of iron are actually present in the interior of the earth, as has been assumed from the earth's specific gravity.

Sir Norman Lockyer in a recent work, *The Meteoritic Hypothesis* (1890), has attributed a very important part to meteorites in cosmology. He regards all luminous cosmic bodies as masses which have originated from swarms of meteorites, or from the collision of vapours to form a cosmic sphere.

Geogeny.—During the nineteenth century speculations regarding the earth's origin followed for the most part the nebular theory of Kant, Herschel, and Laplace, and assumed that the earth, in common with all other cosmical bodies, originated by the condensation of some part of universal matter. It was raised to a glowing heat during the process of condensation, and after a protracted period of cooling a solid crust began to form on the exposed surfaces.

This theory was further established by Fourier in 1820, and by Poisson in 1835. Nevertheless, the Neptunian doctrine which had flourished in the end of the eighteenth century, under the influence of Werner, was again resuscitated, and its adherents passed under the name of Neo-Neptunists. The Munich chemist Fuchs was the leader of the Neo-Neptunists, and amongst his followers were Schubert, Schafhäutl, and Andreas Wagner. Their conception of the beginning of the earth was literally the same as that given by the Bible, "In the beginning the world was empty and void."

The Neptunist idea that the solid materials of the earth had originally been held in solution by a primæval ocean, no longer harmonised with the advance of chemical knowledge. Hence the Neo-Neptunist leader depicted the primitive earth as amorphous in constitution, silicic and carbonic acid having united all the component particles in a pasty mass. The formation of rock-material began with the separation of the silicates. Light and heat developed as crystallisation proceeded. The earth became self-luminous, and "certain effects were produced which have a resemblance to volcanoes." Different kinds of rock separated from the primitive amorphous substance, such as granite, syenite, porphyry, gneiss, crystalline schists, greenstone, slates; and afterwards sandstone, quartziferous sand, clay, and flint. A calcareous series formed contemporaneously with the siliceous rock-series, the calcareous rocks then becoming more strongly developed in proportion as the siliceous rocks were less developed. A carboniferous series of rocks began with the formation of graphite and anthracite, reached its maximum in the Carboniferous period, and closed in the youngest mountain-ranges with brown-coal and turf.

Although the theory of Fuchs was so fantastic that it was practically ignored by geologists, it had at least the merit of calling attention to a possible origin of granite, gneiss, schists, etc., in some other way than from a *molten* magma. Schafhäutl was one of the few geologists who accepted the theory of the aqueous origin of crystalline rocks, as he had himself succeeded in producing quartz crystals artificially under the action of superheated water.

Amongst the writers who supported the nebular theory, the French physicist Ampère was one of the most distinguished. In 1833 he published his "Théorie de la Terre" in the *Revue des Deux Mondes*. Ampère held the view that during the gradual cooling of the earth, the substances arranged themselves in the succession of their melting-points. Irregularities in the arrangement of the materials were explained by Ampère as a result of chemical processes which caused a rise of temperature, renewed melting and eruption of masses that had already solidified. Ampère further supposed similar chemical processes to be still in progress in the interior of the earth, and to be the chief cause of mountain-making, volcanoes, and earthquakes.

In 1834 Henry de la Beche published his admirable work entitled *Researches in Theoretical Geology*. He described the earth's matter as originally in a gaseous condition, condensation having taken place in consequence of the constant radiation of heat from the earth's surface. Gradually there formed round the inner glowing nucleus a zone composed of heavy metallic substances, beyond which was a region of lighter, molten oxides, and externally a mantle of vapours and gases. The zone, rich in oxygen combinations, afterwards consolidated as a firm crust of crystalline rocks, which protected the inner nucleus and prevented its complete cooling, while the outer vapours condensed in the form of oceans upon the solid crust.

The Cambridge physicist, W. Hopkins, in a series of papers (1839-42) investigated the internal constitution of the earth by means of mathematical calculation. Assuming that the earth was originally molten, then three possibilities are set forth by Hopkins as a result of cooling:—

1. An outer solid crust surrounds a nucleus that is still molten, or
2. The earth's sphere is surrounded by a firm crust, and contains a solid nucleus, both separated by a zone of molten material, or
3. The earth may be completely solid.

Hopkins calculated that the solid crust of the earth had a thickness of about $\frac{1}{4}$ or $\frac{1}{5}$ of the earth's diameter—that is, at least one hundred and seventy-two to two hundred and fifteen geographical miles. A direct communication of the internal molten material with the surface of the earth was therefore impossible in Hopkins's opinion, and he concluded that the volcanoes must draw their molten material from reservoirs of moderate size *within* the solid crust of the earth.

At the same time as Hopkins was following out his mathematical and physical calculations, Bischof in Bonn was making experiments similar to those which had previously been attempted by Buffon. Bischof caused large balls of basalt to be melted, and observed the time required for the cooling of the melted basalt. By the application of the results to the rate of cooling of the earth, Bischof calculated that the complete solidification of the earth would occupy a period of three hundred and fifty million years. Naturally, the application of results obtained upon such a small experimental scale cannot be relied upon in any accurate scientific sense. It was shown

by Sir William Thomson (Lord Kelvin), in his famous paper "On the Secular Cooling of the Earth" (1862), that even mathematical methods could not lead to any definite calculation of the age of the earth. According to Thomson and Tait's *Handbook of Theoretical Physics*, the formation of a solid crust took place not less than twenty million years ago, and not more than four hundred million years ago. Helmholtz calculated, upon the basis of the original temperature of the earth-vapour, that the age of the earth might be sixty-eight million years.

In 1893, the American geologist, Clarence King, published a paper "On the Age of the Earth." He supposes the earth to have been originally molten, and now to have a solid nucleus and a solid crust, and a zone of molten material between crust and nucleus. From a number of observations and experiments, King concludes that the original temperature of the earth was not more than 2000° C., and that its age might be about twenty-four million years.

A remarkable theory of the earth's constitution was presented by the chemist Sterry Hunt in Canada. He starts from the hypothesis of a homogeneous, gaseous, rotating sphere, in which the parts undergoing condensation seek the centre; there they again become heated, and are kept circulating, finally settling down in zones according to their density and forming a molten, plastic sphere. The consolidation of this sphere begins in the central region. Slow cooling also goes on at the surface of the molten mass, and chemical combinations are effected there owing to the pressure of atmospheric vapours. Gradually a crust forms permeated with water, and in its lower horizons more immediately affected by the internal heat of the earth, the inner crust is again melted and forms a plastic watery zone between the solid, heated nucleus and the outer crust. This intermediate zone is the centre of volcanic action, of earthquakes, and of deforming changes in the earth's crust.

Another ingenious thinker in this subject was Robert Mallet (1810-81), a civil engineer in Dublin. Mallet thought that the cooling of the original molten sphere began at the Poles. Certain portions, as they solidified at the Poles, sank into the molten mass, but again rose to the surface at the equatorial regions and began to return towards the Poles, the circulation of rock-material being analogous with that of the ocean currents at the present day. The formation of a crust proceeded out-

wards from the Poles. At first it was merely a thin, flexible rind on the viscous or liquid inner mass. Then the crust while still hot, and locally at a red glow, broke and tore; the first rains collected in the depressions, and systems of tensions and pressures were generated in consequence of the subsidence of crust-blocks. A more complete phase of movement was reached as the crust became gradually thicker; forces which had during contraction been acting vertically towards the centre were diverted in a tangential direction by the resistance of the crust, and produced the folds and wrinkles represented in our mountain-chains. Continents and oceans also formed, and the crust was in a state to sustain life. In the fourth or final phase, to which the present belongs, the crust has become very thick; cooling and contraction are now proceeding very slowly; the tangential pressures called forth by the sinking crust are relieved by horizontal compression of the rocks at zones and localities of crust-weaknesses. The work done by pressure and fragmentation is converted into heat; and it was by means of this transmutation that Mallet explained the origin of the earth's own heat, and of volcanoes.

Mallet's explanation was warmly contested by O. Lang and Julius Roth. Lang differed from most physicists and chemists in his opinion that an increase in volume and not a contraction took place during the transition of the earth's material from the molten into the solid state. He attributed the origin of volcanoes to the expansion of the outer rock-materials during their consolidation and the necessity of additional space.

Ries and Winkelmann published in 1881 a series of observations on the solidification of melted metals. Their results were so far favourable to Lang's hypothesis in that they proved that, with the exception of cadmium and lead, nearly all other metals are heavier in the molten condition than in the solid. At the same time, Bischof's experiments are contradictory, since they prove that the most important plutonic rocks, such as granite, trachyte, basalt, suffer considerable contraction in passing from the molten into the solid state.

Faye, whose principles of cosmogony were briefly referred to above (p. 155), also made an attempt to explain the origin and development of the earth in agreement both with the doctrines of modern astronomy and with those of geology and palæontology. Starting from his own standpoint that the earth and

the inner planets were in existence before the sun, Faye supposes that the first traces of organic life on the earth originated under the diffuse light of the still unconsolidated sun, that a uniform climate reigned over the whole earth during the Primary epochs, and that consequently the distribution of plant and animal life cannot, as is frequently stated, have proceeded from the Poles.

CHAPTER II.

PHYSIOGRAPHICAL GEOLOGY.

THE subject of physiographical geology coincides in essential features with that of geophysics (or physical geography). The only distinction that may be drawn is that while physical geography deals more with the description and exact determination of the physical properties of the earth's body, physiographical geology concerns itself more with the causes and effects of these relations. It is, however, impossible to define a strict line of division between the studies of geography and geology.

Certain questions about the physiography of the earth had been discussed by the Greek philosophers, and the knowledge of the ancients in this domain had in all probability been comprised in a book of Theophrastus. Unfortunately the book has been lost, and is known to us only through excerpts from it that appeared in the works of later geographers.

The first work that merits the name of a physical description of the earth is the famous *Geographia Generalis* of Bernhard Varenius (Amsterdam, 1672). In 1661 the comprehensive work of Riccioli, and in 1664 that of Kircher, appeared; nearly a hundred years later followed the important geographical and physiographical text-books of the Dutchman Lulofs (1750) and the Swede Tobern Bergman (1769). Bergman's work was taken as a model by the famous Werner in his teaching of geognosy, and thus its style and general treatment came to be handed down in the later text-books published by pupils of Werner. All the text-books of the Wernerian school, especially those of Fr. Ambros Reuss, F. R. Richter (Freiberg, 1812), and K. A. Kühn (Freiberg, 1833), contain a full account of physiographical geology.

In France, Buache had in 1756 kept physical geography

within narrower limits than his contemporaries; on the other hand, Desmarest in 1795 began a very large work in the *Encyclopédie Méthodique*, in which he treated the subject in the wide sense more generally accepted at that time.

No less a scientist than Immanuel Kant was the first in Germany to hold academical lectures on physical geography. Kant's lectures were published in text-book form at Königsberg in 1802. They contained nothing remarkably new, yet an importance attached to them as the first attempt to collect the subject-matter within concise and definite limits.

In the years 1827 and 1828 Alexander von Humboldt delivered his famous lectures at the Berlin University and the Academy of Singing. Under the inspiring influence of this great geographer, Friedrich Hoffmann prepared his interesting work on physical geography (1837). Almost simultaneously, in the year 1836, Heinrich Berghaus published at Gotha a Physical Atlas which contained a collection of maps presenting the facts of physical geography in a manner that at once appealed to the eye and understanding. This graphic treatment of the subject marked a new and successful departure in geography, which was immediately imitated in other countries. The excellent Physical Atlas of the Scottish publisher, Keith Johnstone, is essentially an imitation of the Berghaus Atlas, increased by a few special maps of Great Britain, and some additions contributed by two German colleagues, H. Lange and A. Petermann. The Geographical Institute at Gotha kept its leading place in cartographical science, and published between the years 1886 and 1892 a new and enlarged edition of the original atlas of Heinrich Berghaus, under the editorship of his nephew, Hermann Berghaus.

The year 1845 will ever be remembered in geographical science as the date of the publication of the first volume of Alexander von Humboldt's great work, *The Cosmos.* This magnificent physical description of the world gives a complete account of the knowledge of natural science in all civilised races up to the middle of the nineteenth century. It is a more extensive work than had ever before been undertaken by a single individual, and a work that is not likely to be attempted again in the future. As Peschel has said, Humboldt's *Cosmos* comprises thousands of facts, of measurements, and of calculations reckoned according to the most exact scientific

methods which were then known; it is an *imago mundi*, or mirror of the world, of the most faithful kind.

Immediately before the publication of Humboldt's *Cosmos*, in 1844, Bernhardt Studer, the Swiss geologist, published a text-book of physical geography and geology, which is remarkable for its clearness of disposition, mastery of the subject, familiarity with the literature, and conciseness of treatment.

Numerous text-books of physiographical geology appeared in the latter half of the nineteenth century; amongst others may be mentioned those of Oscar Peschel (1879), of Siegmund Günther (new ed., 1897-99), the popular *La Terre* of Elisée Réclus (1868-69), those of Hann, Brückner, and Kirchhoff, and the able chapters in Sir Archibald Geikie's *Text-book of Geology* (3rd ed., 1893).

Form, Size, and Weight of the Earth.—The determination of the form, the size, and the weight of the earth, although of great interest to geologists, is more especially the domain of the geographer, and cannot here in the narrow limits of space be treated with historical detail. Suffice it to state the present standpoint of our knowledge. For the actual form of the earth, with its numerous deviations from the spheroid of rotation, Listing proposed in 1872 the name of "Geoid," and it is at present one of the chief tasks of the International Commission for the measurement of the degree to arrive at the true form of the geoid.

The form of the geoid, however, cannot be discovered merely by trigonometric methods; probably the pendulum will play an important part in the future solution of the problem. It has already been demonstrated that the oscillations of the pendulum do not everywhere depend upon the distance from the earth's centre; it is more especially in the interior of continents that the deviations indicate a diminution in the force of gravity. Faye is therefore of opinion, that in consequence of the stronger cooling, the earth's crust is denser under the floor of the ocean than under the continents. Helmert, Hergesell, Drygalski, and others, have supported Faye's hypothesis in its main features; they are of opinion, however, that the attractive force exerted by continents on neighbouring ocean surfaces is more or less compensated for by the smaller density of the earth's crust under the continents.

The pendulum observations made by Von Sterneck in the

eastern Alps and Carpathians yielded results which showed as a rule relative "defects of mass" in the mountains, and "surplus of mass" in the plains, and such results suggested in geological circles a correlation between crust-movements and conditions of density in the crust. But, since the publication of these measurements, more recent observations taken in the leading European and foreign observatories, have led to the conclusion that there is no immediate connection between the density of the earth's crust and the tectonic structure of the crust.

Pendulum observations are even more important for the determination of the specific gravity of the earth than for questions regarding its form. According to the law of gravitation, the action of two masses is proportional to their size, and inversely proportional to the square root of the distance of their central points of attraction. Hence if a body be simultaneously subjected to the attractive forces of the earth, and of another mass of some considerable gravity, the density of the earth may be calculated from the result.

The two Scotsmen, Maskelyne and Hutton, made in the years 1774 to 1776 a series of admirable experiments at the mountain of Schiehallion, in Perthshire. Their aim was to arrive at the density of the earth by means of the pendulum deviations in the presence of the mass of Schiehallion. The size, form, and weight of the solitary mountain were calculated by trigonometry, and the local deviations of the pendulum were observed as the pendulum was brought into the neighbourhood of the disturbing mass of Schiehallion, the result was a gravity of 4.713 for the earth. Observations have since been taken at many different parts of the world, and various figures have been in later years given for the earth's gravity (4.39, 6.62, and 5.77).

All determinations of the earth's gravity agree in showing that the gravity of the earth as a whole is very much greater than the gravity of the rocky crust, which has an average gravity not exceeding 2.5. Thus we know the important geological fact that the interior of the earth is neither empty nor can it be filled with water, but it must consist of substances of very great weight.

The Earth's Internal Heat and the Constitution of its Interior.—It has long been known that the heat of the sun

and the atmosphere influences the temperature of the ground only to a limited depth below the surface. It was determined during the eighteenth century that external influences are perceptible only within depths of about 30 feet, or as far down as 80 feet, according to the geographical position of the locality. At the so-called "neutral" zone, or critical horizon of depth, there is a constant temperature which practically corresponds with the average annual temperature of the particular place. Below this zone of constant temperature, the temperature increases in mines, and the increase can only be attributed to the earth's own heat. This increase of temperature had already been noted by Kircher and Boyle in the seventeenth century, but it was not until 1740 that definite observations were made by Gensanne in the lead-mines of Giromagny in the Vosges. Gensanne's result demonstrated an increase of 1° C. for 114 feet of depth. Measurements were made in 1790 and 1791 in the Freiberg mines by Freiesleben and Alexander von Humboldt; Lean took observations in the Cornwall mines, Fantonetti in Italian mines, and Alexander von Humboldt in South American and Mexican mines. All these observations were based upon the temperature of the air in the mines. But, as it was pointed out by Cordier and Reich, this temperature is influenced by air currents, by the mining work, and by the breath of the miners and of animals. Cordier and Reich then placed the thermometer in the rock itself, and taking necessary precautions for correction of experiments, arrived at results of a more reliable character. Cordier reports from French mines an average increase of temperature of 1° C. for 25 mètres (*circa* 77 feet), while Reich reports grades of 41.84 mètres (*circa* 129 feet).

Since 1828, temperature observations have been continuously taken in the mines of Saxony and Prussia, and these yield an average of 1° C. for 167 feet, but as the variations range from 48 to 355 feet, it is impossible to draw any definite law. In England, the British Association for the Advancement of Science about twenty years ago appointed a special commission for investigations of the ground temperatures, and the relative capacities of heat conduction shown by different rocks. A great number of observations have also been contributed by other lands, but as yet no definite results have been obtained. The ground-borings made in various countries have afforded a means of taking observations on the increase

of temperature; generally speaking, they show an increase of 1° C. in grades of about 30 to 34 metres (104 to 118 feet). The results yielded by borings have been confirmed by observations in the great Alpine tunnels.

The Italian geologist, Giordano, published in 1870 exact observations made in the Mont Cenis tunnel, and the German civil engineer, Stapff, published those in the St. Gothard tunnel (1877-80). In the middle of the Mont Cenis tunnel the rock has a temperature of 29.5° C.

In spite of the numerous local variations in the exact rate of increase of temperature, there can be no doubt that the temperature of the ground increases so far as depths below the surface have yet been reached; the probability is that at still greater depths still greater increase of temperature takes place. Hot springs in many cases rise from great depths, and cannot be shown to have connection with volcanoes or with any particular geological formation.

Calculations have been made with respect to the probable rate of progression in the increase of temperature at depths still unattained, but the results cannot be regarded as trustworthy. Thus, although all geologists agree that the rise of temperature in the earth's crust is due to the internal heat of our planet, we have not yet sufficient data to determine either the prevailing inner temperature or the thickness of the earth's crust.

At the same time, the hot springs and geysers indicate temperatures that reach the boiling-point in the earth's crust, and the wide distribution of volcanoes demonstrates still higher degrees of temperature in the crust. The scientific authorities in the first half of the nineteenth century regarded it as an accepted fact that the earth's nucleus was molten, and was surrounded by a comparatively thin crust. Humboldt and Élie de Beaumont valued the thickness of the earth's crust at 40 to 50 kilometers, and this result almost agrees with the more recent work of the Rev. O. Fisher, who valued the thickness at 25 English miles. But the calculations made by various authorities differ very considerably, some calculations giving a result of only 14 English miles for the thickness of the earth's crust, others a result as great as 75 English miles.

The great chemist, Sir Humphrey Davy, did not believe in the original molten condition of the earth's nucleus. He believed that the earth's nucleus was originally composed of

the earthy and alkaline metals, and that its prevailing high temperature was due to chemical processes. Davy's explanation afterwards found favour with De la Rive and Charles Lyell. Volger explained the heat of the earth partially as a product of the pressure which the higher mountain-systems exert upon the regions underlying them, partially as a result of the chemical changes constantly going on in the earth's crust; and the Ultraneptunist chemist, Mohr, in his *Geschichte der Erde* (1866), explained the internal heat of the earth as a transmutation of the sun's energy by chemico-physical processes.

Lichtenberg and Franklin thought that the firm earth's crust surrounded a half-gaseous, half-viscous mass of very great density. This opinion was accepted by Herbert Spencer, and has since been placed upon the basis of the Mechanical Heat Theory by Ritter (1879) and the geographer Zöppritz (1882). According to this theory, there is under the firm crust a zone of viscous material, then a zone of more fluid material; the earth's nucleus itself, however, is said to consist of an outer gaseous part, in which the gases are in their normal condition, and an inner gaseous part, in which they are above the critical point. Owing to the excessive pressure, the gaseous material of the earth's nucleus is said to become no less dense than liquid or solid bodies.

The English physicist, Hopkins, has been one of the most famous champions of the theory of the earth's rigidity. Seeing that the earth behaves as a firm mass in response to the attraction of other bodies in the universe, and that the phenomena of precession and nutation are not consistent with an even partially fluid or plastic condition of the earth, Hopkins concluded that the earth has been rendered for the most part solid, in consequence of the cooling and of the great pressure within the earth. Like Hopkins, Poisson and Ampère (1868) were also of opinion that the earth's nucleus could not be fluid, as otherwise the attraction of the moon would cause gigantic tidal waves to take place in the firm crust.

The physicists, Lord Kelvin (Sir W. Thomson) and George Darwin, also attribute great importance to the enormous pressure existing in the interior of the earth, and the consolidation of the nucleus from this cause. Darwin agrees with Hopkins in respect of the behaviour of the earth relative to the sun and the moon, and tries to prove by calculation that

if the earth's nucleus were molten, phenomena similar to ebb and flow would be induced which could only be resisted by a crust of enormous thickness, *circa* 2000-2800 English miles thick. Besides, if the earth's body were plastic, the oceanic tides would not only be induced by the attraction of the sun and moon, but would also be influenced by deformations of the earth-spheroid. There are, however, no indications of this disturbing influence. Darwin therefore believes that the earth behaves as a rigid body and possesses probably a viscous-elastic constitution.

Lord Kelvin has essentially the same opinion, and ascribes to the body of the earth a degree of rigidity intermediate between that of steel and of glass. Starting from the nebular theory, Lord Kelvin (1862, 1879) supposes that the cooled and thereby heavier masses sank inward and formed an initial central nucleus, which always extended towards the periphery as the earth's mass continued to cool, until finally almost the whole earth became rigid. Ries and Winkelmann contested (1881) this hypothesis on the ground that not only a number of metals, but also silicate combinations undergo a decrease of density at the moment when they become solid, so that they could not sink in a molten mass.

The American, Barnard, wrote in 1877 a paper on the internal structure of the earth, considered as affecting the phenomena of precession and nutation. He agreed with Hopkins and Darwin that the behaviour of the earth under the attraction of other bodies in the universe shows a very high coefficient of rigidity for the earth's mass. Reyer in Vienna in the same year brought forward arguments in favour of the theory of rigidity, but supposed that the rigid magma of the nucleus was saturated and impregnated with solvents and gases in so great a degree, that whenever the pressure of the crust was relieved or modified by fractures the nuclear material could readily become viscous or fluid, and capable of eruptive action.

In opposition to the adherents of the earth's rigidity, many geologists retain the older view, at least in part, in so far as they believe there is a zone of molten magma under the firm crust, and do not accept the extreme conception of the rigidity of the nucleus.

Sterry Hunt advocated the view that the originally molten globe began to solidify in its central part. At the surface,

great pressure was exerted by atmospheric vapours of water, and the molten material became saturated with these. Chemical processes took place, and gradually a firm crust formed. The lower layers of this crust came by degrees into the sphere of influence of the earth's own heat, and were there converted into a zone of "watery magma." This intermediate zone between the crust and the firm nucleus is, according to Sterry Hunt, the particular region in which plutonic and volcanic eruptions take origin. ("The Chemistry of the Primæval Earth," *Geol. Mag.*, 1868-69.)

Dana expressed the opinion that about two-thirds of the earth's mass are composed of iron, and form a rigid nucleus above which a viscous, hot magma forms an intermediate zone, while beyond that zone the earth's crust has a thickness of about seven or eight miles. Amongst other investigators, O. Fisher strongly advocated a molten viscous condition of the earth's nucleus upon which the firm crust rests. Within recent years it has become customary to apply a certain definite terminology to the various zones of the earth's spheroid, in accordance with the supposed physical condition of each particular zonal region. Thus Sir John Murray, in his Presidential Address (Geogr. Sect. Brit. Assoc., 1899), said: "When we regard our globe with the mind's eye, it appears at the present time to be formed of concentric spheres, very like, and still very unlike, the successive coats of an onion. Within is situated the vast nucleus or *centrosphere;* surrounding this is what may be called the *tektosphere* (*tektos*, molten), a shell of materials in a state bordering on fusion, upon which rests and creeps the *lithosphere*. Then follow *hydrosphere* and *atmosphere*, with the included *biosphere* (*bios*, life). To the interaction of these six geospheres, through energy derived from internal and external sources, may be referred all the existing superficial phenomena of the planet."

Recent seismological observations indicate the transmission of two types of waves through the earth—the condensational-rarefactional, and the purely distortional—and the study of these tremors supports the view that the centrosphere is not only solid, but possesses great uniformity of structure. The seismological investigations of Professors Milne and Knott point also to a fairly abrupt boundary or transition surface, where the solid nucleus passes into the somewhat plastic magma on which the firm upper crust rests.

Morphology of the Earth's Surface.—In a general way Strabo, Seneca, and Ptolemy had discussed the geographical distribution and individual forms of the elements that make up the surface configuration of our globe. But the works of Cluverius, Nathanael Carpenter, Kircher, and Varenius in the seventeenth century, contain the earliest attempts at systematic treatment of surface forms according to their mode of origin. From the seventeenth century to the present day the study of the earth's configuration may be said to have gone hand in hand with that of geology, for the theories which at any time prevailed amongst geologists were not without influence upon contemporary views regarding the surface forms.

Hutton and Playfair drew attention to the marked effects of water and heat upon the earth's surface; and Werner and his followers showed the connection between the geological structure of the ground and the particular distribution of surface forms—continents, islands, mountain-chains, solitary mountains, plateaux, valleys, etc. The first accurate and convincing proofs of the relation between geological structures and the shapes of mountains were given by Pallas and by De Saussure, who was the first to carry out the complete ascent of Mont Blanc.

As our geographical knowledge widened, the necessity made itself felt of grouping the scattered and fragmentary facts together and deriving from them some general principles of surface morphology. An effort in this direction was made towards the end of the eighteenth century by Reinhold Forster, whose *Bemerkungen auf einer Reise um die Welt* (1783) contained a formal treatment of such features as the shape of the continents, the structure and position of islands, coastal forms, and coral reefs.

But the ever-increasing love of travel found its first inspired scientific exponent in the great Humboldt, whose wonderful descriptions of his personal impressions of natural landscapes and form were as artistic as his classification and distinction of structural types in tropical America and in Central Asia were masterly. Humboldt's writings bore essentially the stamp of an eye-witness, and were concrete in character. The works of Carl Ritter, his *Erdkunde* and books of travel, were abtruse and teleological, the works of a student and thinker. Richthofen writes of him: "Never have all the known facts regarding a group of geographical areas, never

have all the researches and observations of others, been combined with greater completeness or with clearer philosophical conceptions than by Ritter in his monumental work on Asia. He has endeavoured to replace the meagre descriptions of his predecessors by a chorological representation; he has gathered information from the most varied sources and kneaded it into an organic and intellectual whole, united by the principle of causality." (*The Tasks and Methods of Modern Geography*, Leipzig, 1883.)

During the latter half of this century the abundance of new facts brought home by travellers of all nations has extended our knowledge with remarkable rapidity. But the treatment of the subject remained for a long time of the more formal and descriptive character. Most travellers contented themselves with descriptions more or less accurate and with measurements, and were indifferent to the genetic aspects of geography.

If we except the older works, that of Humboldt may be said to have laid the scientific foundation of a morphological treatment of surface forms. His calculations of the average height of the great continents form the starting-point of a series of investigations, amongst which may be mentioned those of A. de Lapparent (1883), Von Tillo (1889), John Murray (1886), and of a number of eminent younger geographers. By the side of orography, oceanography has made even more remarkable progress during the century, and has developed itself into an independent branch of the morphology of the earth's surface. Otto gave in 1808 a fairly complete account of the limited facts then known about ocean forms. Great advances had been made when the American sailor Maury published his excellent work fifty years later. Maury gave a general idea of the extent of the ocean surfaces, the forms of coast-lines, the ocean tides and currents, the physical and chemical conditions of the water and the various organisms that inhabit the oceans, and was also enabled, with the help of three lines measured for the laying of the Transatlantic cables, to sketch the first section and the first map of the floor of the North Atlantic ocean. From these data Peschel in 1868 calculated the mean depth of the North Atlantic Ocean.

A new era began in oceanography with the exploring expeditions of the English *Challenger*, the German *Gazelle*,

and the American *Tuscarora*, all of which were carried out almost simultaneously in the years 1872-77. These were followed by a series of similar undertakings.[1]

The seas were investigated in all latitudes and in all zones by means of plumb-line soundings and deep-sea thermometer readings; and the ocean sediments were brought from different horizons of depth by dredging-nets. In the year 1843, Humboldt had known no greater depth than 2000 metres. From the large number of observations taken by the *Challenger* and *Tuscarora* expeditions, Samuel Haughton was able in 1876 to calculate the mean depth of the Pacific, Atlantic, and Indian Oceans at 3000 to 3,650 metres. Krümmel in 1878 made a most careful and accurate calculation from all known data, and gave the mean depth for all oceans at 3,438 metres.

The old hypotheses of Athanasius Kircher, Kant, Ritter, and others, about submerged mountain-systems and submarine prolongations of continents had to give place to the newly obtained data. It was found that the greatest ocean depths were not in the middle of the oceans, but as a rule along the edge of mountainous coast-lines. The floor of the ocean has its different horizons of level: smooth ridges, extensive plateaux with gentle slopes, narrow canal-like depressions, connected series of deep hollows extending to depths of 6000 metres, and even 8,500 metres below sea-level, and undulating crust-forms occur in all the great oceans; but under the water there are no toothed mountain summits, no steep arêtes, no valleys and ravines such as we are familiar with amongst the surface forms of the land produced by subaerial erosion.

The material brought up by dredging-nets shows the nature of the sediments that are in course of deposition on the ocean-floor. "On the continental shelf, within the 100-fathom line, sands and gravels predominate, while on the continental slopes beyond the 100-fathom line, blue muds, green muds, and red muds, together with volcanic muds and coral muds, prevail, the two latter kinds of deposits being, however, more characteristic of the shallow water around oceanic islands. The composition of all these terrigenous deposits depends on the structure of the adjoining land.

[1] A complete account of the expeditions which have contributed to our scientific knowledge of oceanography has been given up to the year 1883 in Boguslawsky's *Handbuch der Oceanographie*, vol. i., pp. 390-400.

"The materials composing pelagic deposits are not directly derived from the disintegration of the continents and other land-surfaces. They are largely made up of the shells and skeletons of marine organisms secreted in the surface-waters of the ocean, consisting either of carbonate of lime, such as pelagic Molluscs, pelagic Foraminifera, and pelagic Algæ, or of silica, such as Diatoms and Radiolarians. The inorganic constituents of the pelagic deposits are for the most part derived from the attrition of floating pumice, from the disintegration of water-logged pumice, from showers of volcanic ashes, and from the *débris* ejected from submarine volcanoes, together with the products of their decomposition." (Sir John Murray, Brit. Assoc., 1899.)

Throughout the earlier parts of the nineteenth century much labour was expended on the description of different parts of the continents, but the treatment was too formal to advance the conceptions of the connection between the physiography and geology of the earth. A desire gradually made itself felt, not only to describe, to measure, and to compare the actual forms and to follow their distribution, but also to explain their origin and development; and the two sister studies more fully recognised their community of aim. The physical exposition of the Swiss Jura mountains by Thurmann, in 1832, gave a strong impulse to the new direction of thought in Europe, but it was in the wide plateaux of America that the first signal successes of physiographical geology were won. The brilliant works of Dana and Leslie were followed by those of Powell, Dutton, Gilbert, and other pioneer geologists in the Far West; by their vivid portrayal of the work of subaerial denudation the American writings roused the intellectual life of the middle of the century to new conceptions on a grand scale.

The gigantic erosion forms in the Bad Lands, the configuration of the Rocky Mountains and of the plateaux lands in Arizona, Colorado, and Mexico, the wonders of the Yellowstone Park and California, called forth a new and rich literature, which demonstrated in the most convincing way that the surface-forms of those regions are mainly the result of the erosive activity of water.

Davis, MacGee, Chamberlin, and others have worked along the same lines in the east of North America and the middle States, where ice rather than water takes the first rank as the agent which sculptured the prominent surface-forms.

Independently of the Americans, the writings of Sir Andrew Ramsay, and of Sir Archibald Geikie and Professor James Geikie in Scotland, gave convincing evidence of the work of ice and water upon the rocks. Rütimeyer contributed in Switzerland a brilliant paper on the formation of valleys, while Desor elucidated the leading features of desert and moraine landscapes, and his teaching found able followers in Heim, Baltzer, Fellenberg, Du Pasquier, and Penck. De Lapparent and De Margerie in France, Torell and Helland in Scandinavia, Muschketow and Lewakowsky in Russia, are the leaders in this direction of study.

In 1869, Oscar Peschel had collected the principles of physiographical geology into a systematic form, and thus given the first incentive towards converting the study of this subject into an independent scientific discipline. Instead of the earlier formal grouping of the surface-forms, the treatment of the subject now betokened an effort to group together all types of form which have a similar genetic history. What Peschel tried to initiate in this direction was fully realised by Baron von Richthofen in his book, *Führer für Forschungsreisende* (Berlin, 1886). This work, designed primarily as a guide in the methods of observation, is based for the most part upon the personal observations of the author during many years of travel in the Alps, Carpathians, North America, and China, and has become in Germany the standard work for the systematic treatment of surface-forms.

In 1894, Penck accomplished the difficult task of arranging our present knowledge of surface-configuration upon the basis of leading genetic principles. In his *Morphologie der Erdoberfläche*, Penck has presented the chief results of the special literature of physiography in clear, concise form. A comparison of Richthofen's *Führer* and Penck's *Morphologie* with the older works on orography and hydrography, shows very plainly the great improvement that has been effected by the new methods of study in the domain of geography.

CHAPTER III.

DYNAMICAL GEOLOGY.

In the days of the Greek philosophers attention had been frequently directed to the changes in the surface conformation of the earth, and the natural forces which produce them. Herodotus, Aristotle, Strabo, Seneca, Pliny, and others contributed valuable information regarding wind and weather, springs, water-courses, inundations, and earthquakes. A systematic treatment of these agencies, with reference to the changes produced in the earth's surface, was first carried out by the Belgian mathematician, Simon Stevin (1548-1620). But it was not until two centuries later, after the physical investigation of the earth's surface had been conducted along scientific lines, and had shown the influence of these agents upon the existing conformation of the earth's surface, that geologists began to correlate the past changes in the earth's surface with similar natural causes. Then dynamical geology gradually developed as a branch of study intermediate between geography and geology, which was fostered from both sides, and proved useful to geography in so far as it elucidated the present constitution of the earth's surface, to geology in so far as it served to explain the successive phases in the earlier ages.

Hutton and Playfair had expressed the view that all earlier geological events were explicable upon the basis of the forces and phenomena still in action. The Scottish geologists had pointed out the importance of realising the high antiquity of our earth, and the gigantic work that might be accomplished by physical agencies small in themselves but acting throughout long periods of time. The fame and authority of the great Frenchmen, Buffon and Cuvier, lent support, on the other hand, to the conception of repeated earth catastrophes. Approaching the subject, as they did, from the standpoint of

the natural historian, rather than from the more critical standpoint of the physicist, chemist, or geologist, the French scientists and their adherents were impressed by a sense of the utter disproportion between the infinitesimal changes now taking place under the eye of man and the magnitude of the topographical and biological changes evinced in the remote past. Changes of such magnitude must, they argued, have been the result of stupendous revolutions in the organic and inorganic world, revolutions whose causes and effects were different both in kind and in degree from any known phenomena of the present age.

The "Catastrophal Theory" met almost simultaneously in Germany, France, and England with strong opposition. In the year 1818 the Royal Society of Sciences in Göttingen, acting on a suggestion of Blumenbach's, offered a prize for the best "*investigation of the changes that have taken place in the earth's surface conformation since historic times, and the application which can be made of such knowledge in investigating earth revolutions beyond the domain of history.*"

This subject was handled by Carl Ernst Adolf von Hoff with brilliant success. The first volume of his great work treats of the relation between land and sea in historic time, the extension of the ocean surface owing to the erosion of the coastal territories and invasions of the continents. The volume betokens complete mastery of all the literature on the subject, from the authors of antiquity to the nineteenth century. Von Hoff proves the baselessness of the tradition of a buried city, Vineta, on the Pomeranian coast, and regards with scepticism the alleged discovery of an old map in Heligoland with geographical details of this island in the ninth, fourteenth, and seventeenth centuries. This map was found afterwards to have been fabricated. The origin of the Bosphorus and the Strait of Gibraltar as invasions of the Black Sea and the Atlantic Ocean respectively is held to be probably correct by Von Hoff, but he disputes the occurrence of these events within historic time. With scholarly skill, Von Hoff proves that the Platonic "Atlantis" and the submerged island of "Friesland" can only be regarded as fables. An excellent description is given of the changes occasioned along the seaboard by the deposition of sediments, and is illustrated by reference to the Nile delta, the recent formations on the north coast of Africa, Syria and Asia Minor, the Black Sea, in the

Greek Archipelago, in the Adriatic and Tyrrhenian Seas, on the north coast of the Mediterranean Sea, and on the shores of the Atlantic Ocean, the North and Baltic Seas.

The second volume treats of volcanoes, earthquakes, and geysers. The author brings forward no new hypothesis about the causes of these phenomena, but follows largely the views of Von Humboldt and Von Buch. The chief merit of Von Hoff is his careful epitome of all reliable information regarding the changes and disturbances which have been produced by volcanoes and earthquakes within historic time.

Ten years elapsed between the appearance of the second and the third volume of Von Hoff's work. During the interval the first volume of Charles Lyell's *Principles of Geology* was published, and its influence upon Von Hoff is quite apparent in the third volume of his work. In this third volume, Von Hoff discusses the causes of the degradation of land. The changes in surface conformation and the gradual destruction of a continent are referred to atmospheric agencies, to the chemical and mechanical action of water, snow, and ice, to living organisms, and to the erosive action and usurpations of the sea over coastal territories. He discredits Buckland's hypothesis of a universal flood in a learned and convincing chapter.

The meritorious work of Von Hoff did not meet with the full recognition which it deserved. This arose largely from the fact that Von Hoff drew his data almost wholly from literature, his modest circumstances not permitting him to visit the localities of which he wrote; his conclusions were therefore based upon historical evidence.

In France, Constant Prévost, quite independently of Von Hoff's work, attacked the catastrophal theory of Cuvier. In 1825, Prévost announced his view that the physical conditions and phenomena of the present age were in every respect similar to those which had characterised the past geological epochs. In 1828, he repeated this opinion, and protested against the frequent inundations by the sea assumed by Cuvier and Brongniart to have taken place in the Paris basin. Prévost's attack upon Cuvier's theory had little effect, as it was not supported by any new data, and he weakened his arguments by allowing that certain geological forces might have developed stronger energies in past epochs than in the present.

The strongest combatant who entered the lists against the catastrophal theory was Charles Lyell,[1] a Scotsman by birth. Like his two older contemporaries, Alexander von Humboldt and Leopold von Buch, Lyell had the good fortune to enjoy an independent patrimony and to be able to devote himself wholly to science. While he was a student in Oxford, he attended Buckland's lectures and showed a great interest in entomology. During one of his vacations he accompanied his parents on a three months' tour through France, Switzerland, and Upper Italy. It was then that Lyell felt his enthusiasm aroused for geological studies. Although he completed his law course in the following years, he spent his leisure hours on geology. In 1823 he was in Paris, where he made the acquaintance of Cuvier, Humboldt, and Prévost, and afterwards made excursions with Constant Prévost in the West of England and in Cornwall. In the same year he visited Scotland in the company of Buckland.

The manuscript of his *Principles of Geology* was almost complete in 1827, but before printing it Lyell felt the necessity of being able to bear personal testimony upon many points. Now followed a period in which he travelled to one place and to another, collecting a large number of new data, and enjoying the intercourse of the greatest geologists of his day. In the companionship of Murchison and his wife, Lyell in 1828 visited Auvergne, the Velay and Vivarais, the Riviera, the neighbourhood of Turin, Verona, and Padua. He then continued his journey alone to Parma, Bologna, Florence, Siena, Rome, Naples and Sicily, and returned home by Paris. His chief interest during these journeys was concentrated upon volcanoes and the young Tertiary formations.

The first volume of the *Principles* appeared in 1830, the second in 1832, and the third in 1833. Meanwhile Lyell continued to enrich his knowledge by frequent journeys to

[1] Charles Lyell (afterwards Sir Charles Lyell, Baronet) was born at Kinnordy, in Forfarshire, Scotland, on the 14th November 1797, and was the son of a rich proprietor and the eldest of ten brothers and sisters. He passed his early childhood near Southampton, where his father had rented a country-house, attended school at Ringwood and Salisbury, studied in Oxford, then settled in London, and spent the rest of his life either in London or in travelling. He died in 1875, and was buried in Westminster Abbey. (T. G. Bonney, *Charles Lyell and Modern Geology*, London, 1895, and *Life, Letters, and Journals of Sir Charles Lyell, Bart.*, edited by his sister-in-law, Mrs. Lyell, 2 vols., London, 1881.)

different parts of the Continent. In 1831 he gave a course of lectures on geology in King's College in London. But Lyell would not undertake the duties of a Professor for any length of time. He resigned his post in order to devote himself exclusively to science. His wife Mary, a daughter of the geologist Leonard Horner, proved a devoted companion in all his journeys throughout their long, happy, childless marriage, and was a zealous helper to him in his work, sparing him many of the laborious researches that might have been arduous for his weak eyes.

The publication of the *Principles* placed Lyell in the first rank of geologists, and won for him universal recognition as a fine observer, an acute thinker, and a master of language. The success of his work was unexampled. In spite of its comprehensive character, six editions of it appeared between 1830 and 1840, a seventh in the year 1847, the eighth in 1850, the ninth in 1853, the tenth in 1866, the eleventh in 1872, and the twelfth shortly after his death in 1875. Throughout the long space of thirty-five years between the first and last editions, Lyell was indefatigable in his efforts to improve the work, to widen his range of knowledge by his annual tours, and to test his opinions by intercourse with his geological colleagues. Lyell was as much at home in the geology of Germany, Belgium, France, Switzerland, and Italy as in that of Great Britain.

In the summer of 1834 he visited Denmark and Sweden, in 1837 Norway, and in 1841 he undertook his first journey to North America. He stayed there one year, on this occasion visiting chiefly Canada and the eastern part of the United States. He published an account of the journey in 1845, in a special work entitled *Travels in North America*. Soon after the publication of this volume, Lyell again crossed to America and investigated the southern states. The account of this journey appeared in another independent volume in 1849, and the work contained, in addition to geological observations, much interesting matter regarding the people and their social, political, and religious relations.

In 1854, accompanied by the German geologist Hartung, Lyell spent several weeks in Madeira and the Canary Isles, where he studied the volcanoes. In his later years he revisited North America twice, and went to Sicily and other parts of Europe, sometimes for the investigation of some

geological question, sometimes for the sake of physical and mental relaxation. The *Principles of Geology* was published originally in four volumes. The first volume deals largely with the climatic variations in the history of the earth, and the influence of these upon local physical conditions and the nature of geological deposits. The second volume treats chiefly of the agencies of denudation and erosion, and comprises special chapters on volcanism. The third volume contains a description of coral reefs, and discusses the various means by which organic remains may be preserved. The fourth volume is devoted to historical geology, and as Lyell in writing it adopted the results obtained in the previous volumes, he produced a geological text-book upon a basis which was at the time quite new. This volume was afterwards published independently under the title of *Elements of Geology*, and passed through six editions before the year 1871.

The author's aim in the *Principles* is described in the alternative title of the work as "an inquiry how far the former changes of the earth's surface are referable to causes now in operation." After an elucidation of some leading conceptions, and a short but excellently written history of geology as far as Cuvier and Brongniart, Lyell discusses the causes of the slow development of his science, and the many false directions into which it had so often been misled.

He shows how theological prejudices and the stubborn adherence to the Mosaic reckoning of time had stood in the way of a right appreciation of the earth's history. The defective knowledge of physical phenomena now in operation on the floor of the ocean and in the interior of the earth had also served to retard the progress of knowledge respecting the formation of the primitive earth-crust. But in Lyell's opinion the greatest stumbling-block had been presented by the quite unphilosophical hypothesis that forces different from any known in the present day had been active in earlier epochs, and that the physical forces still existing had in the past been stronger in their action, and had produced effects which could not now be equalled. Further, the supposition that the sedimentary deposits had originally extended uniformly over the whole earth, as well as the catastrophal theory of sudden changes in the distribution of land and sea, in the climatic relations, and in the organic creation, had, according to Lyell, been hurtful to a healthy development of geology.

The climatic variations during former periods of the earth were discussed by Lyell in considerable detail. He opposed the opinion that climatic changes had been due to the gradual cooling of the earth from an originally molten state, but admitted that during the Tertiary and Diluvial epochs there had been a warmer climate in Europe. During the Secondary epochs reef-corals had inhabited the temperate zones, and in the Carboniferous epoch tree-ferns and other plants indicative of a moist and warm climate had flourished as far north as 75° N. latitude. Lyell traced climatic variations to the varying distribution of land and water, to the influence of ocean currents, to icebergs, and the accumulation of glacier-ice in the polar districts and in the high mountain-chains. He pointed out the geological phenomena characteristic of the Carboniferous epoch —the wide distribution of submarine volcanic products and pelagic limestones, the basin-shaped occurrence of the sedimentary rocks, the absence of large terrestrial and fresh-water vertebrates, the absence of purely fresh-water deposits, and the insular character of the flora. From all these characteristics, Lyell concluded that the northern hemisphere had been covered during the Carboniferous epoch by an island-studded ocean. He then depicted the later epochs, showing that during the Secondary epochs large continents arose in the temperate regions and produced a change of climate; during the Tertiary time the continents in the northern hemisphere became more extensive in the direction of the North Pole, while the Alps, Apennines, and Pyrenees rose as massive mountain-chains, and promoted the gradual approach of the present climatic conditions.

Lyell, in the earlier editions of the *Principles*, attributed little importance to the influence of astronomical causes upon terrestrial variations of climate; afterwards he thought these more worthy of consideration. More especially the changes in the eccentricity of the earth's orbit and in the precession of the equinoxes were treated as important climatic factors, and turned to account in the explanation of the Ice Age.

Having opposed the "Catastrophal Theory" in the first volume of the *Principles*, Lyell tried to establish the uniformity of all natural agencies in past epochs and in the present, and both in the organic and inorganic world.

The subject-matter of the second volume covers the same ground as Von Hoff's work, but while the German geologist

limits himself to a compilation from data recorded in literature, Lyell adds his own observations in confirmation of, or opposition to, received opinions. The geological action of water is first discussed. The destructive and transporting agency of running water is demonstrated by numerous examples, amongst others particular interest attaches to the admirable exposition of the channeling of the Simeto bed at Etna, and the erosion of the Niagara ravine. Lyell, in the earlier editions of this volume, was of opinion that in addition to stream erosion the formation of valleys had been in many cases assisted by the occurrence of earthquakes or landslips, or controlled by local inequalities in the rate of withdrawal of the ocean, but in the later editions he attributed the large majority of valley cuttings to river erosion alone.

Again, in the earlier editions of this volume, ice and glaciers received little attention, but in later editions a special chapter was devoted to them, and Lyell endeavoured to explain the occurrence of erratic blocks as a result of the transportation of rock-material by icebergs and floes.

The chapter on volcanoes and earthquakes includes not only a summary of their distribution and manifestations, but also detailed descriptions of the district of Naples and Etna. In describing Monte Somma, and the volcanoes of the Canary Isles and Santorin, Lyell opposes the theory of "Elevation-craters," and explains the circular walls of inclined strata round a central crater as the ruins of former cones of ejected material. In connection with earthquakes, attention is especially directed to the accompanying phenomena of crust-fissures and alternations of level. The variations at the temple of Serapis, near Pozzuoli, are instanced in illustration of the frequency with which changes of level may take place in opposite senses.

The slower variations of level, independent of volcanism, and affecting large areas, were not fully treated by Lyell in the early editions of the *Principles;* but after his travels in Scandinavia, a chapter on this subject was introduced, and in it Lyell supported the view that the northern portion of Scandinavia was slowly rising.

Lyell attributed volcanoes and earthquakes to the high pressure exerted upon the crust by subterranean vapours and gases which become heated and endeavour to expand. Chemical, electrical, and magnetic influences cause, according

to Lyell, local rise of temperature in the earth's crust, so that larger and smaller reservoirs of melted rock-material may accumulate. If the water and gases impregnating the rocks are converted into vapour, volcanic eruptions and earthquakes ensue. The slow elevations of the ground are also referred by Lyell, in the later editions of the *Principles*, to subterranean rise of temperature and to the consequent expansion of the solid rocks, whereas decrease of temperature or the removal of gaseous material gives origin to subterranean cavities, inthrows, and subsidences.

Lyell was during the greater part of his life an opponent of Lamarckism. In the early editions of the *Principles*, he recognised the occurrence of constant change in the organic world, but refused to associate the modification of living forms with any definite history of evolution during the successive geological ages. He began with the fundamental question whether changes in the animal and plant world were still in progress, or if organic creation had already arrived at its highest development. After discussing Lamarck's views on the production and modification of organs, Lyell enumerated a number of data regarding the limits of variability of wild and domestic species and the results of cross-breeding, and expressed his conviction that each species had been created with the characteristics still presented by it. He allowed that species can to a certain extent accommodate themselves to their environment, but asserted that the possible changes were slight, and rapidly accomplished, having no influence upon the essential characteristics of the species. He held that unlimited variability was further prevented by the natural aversion of species in the wild state to cross breeding, and by the small fertility of hybrids. Lyell afterwards revoked these opinions, a change in his views having been effected by the writings of A. R. Wallace and Charles Darwin.

The two famous papers of these authors on the variability of species appeared simultaneously in the year 1858 in the publications of the Linnæan Society. Darwin's epoch-making work on the *Origin of Species* by Natural Selection was published in the following year, and another work of that year was W. Hooker's *Flora of Australia*.

Lyell, together with the great zoologist Huxley and the philosopher Herbert Spencer, at once enthusiastically accepted

and upheld the newly-founded doctrine of descent. And the tenth edition of the *Principles*, published in 1866, contains an excellent account of the leading principles of Darwin's work and its bearing upon scientific thought. The chapter on the geographical distribution of plants and animals, upon which Lyell had spent considerable care in earlier editions, had to be completely re-written in the light of Darwin's theory. As it now stands, this chapter presents a wealth of fine observations and geological conclusions, and is an admirable model of the scientific treatment of a subject. The extinction of species is explained through changes both in the organic and inorganic world, the appearance of new species is attributed to the modification of progenitors.

In the eleventh edition, Lyell summarised in a special chapter the chief features of his work, *On the Age of the Human Race*, which had been published in 1863. In Lyell's opinion, all human races and sub-races had sprung from a uniform prototype which had originated in one area of the globe. All the early human remains gave evidence that the state of culture of the first ancestors of mankind had been extremely low; and he saw no reason for assuming that man had taken origin through any other agency than the working of those universal laws which had determined the origin of species in the plant and animal kingdoms generally.

In the fourth volume of the *Principles*, afterwards adapted as the *Elements of Geology*, Lyell followed the precedent of Deshayes and Bronn in his sub-division of the Tertiary deposits. He calculated the percentage of living molluscan species present in the successive groups of the Tertiary strata, and upon the percentages fixed a definite basis of sub-division into Eocene, Miocene, and Pliocene formations. Lyell drew his account of pre-Tertiary formations for the most part from the text-books of Conybeare and De la Beche. He applied the term of *primary* formations to the plutonic rocks and the crystalline schists. Lyell opposed the idea that any fundamental distinction existed between plutonic and volcanic rocks, and assumed that granitic and other coarse-grained crystalline rocks might still be in course of formation at great depths below the surface, and under the enormous pressure of superincumbent rocks. He showed that granite had been intruded at various geological epochs, and was by no means invariably the oldest rock, as the Wernerian school had taught. Lyell

proposed the term *metamorphic rock* for the crystalline schists, which he regarded as normal deposits of sand, clay, or limestone, subsequently altered in structure by contact with hot eruptive material and by subterranean heat. Thus Lyell in the question of rock-metamorphism at first preserved precisely the attitude of Hutton, but in later years he ascribed the processes of crystallisation partially to mechanical causes, more especially to strong pressure.

The appearance of Lyell's *Principles* was epoch-making. Since Werner, no geologist had in such a high degree influenced and re-modelled the views of geological science. Although, unlike Werner, Lyell did not impart his ideas directly as a teacher, he was personally on terms of intimate acquaintance with all the greatest of his contemporaries, and no man could better appreciate the value of the latent currents in scientific thought, nor more skilfully render them intelligible to others.

Lyell was a master of clear exposition; his writings appealed to a wide public, attracting many to give more serious attention to the study of geology, and establishing it as one of the most popular branches of science.

Throughout his life he was untiring in his denunciation of any remnants of the unfounded hypotheses promulgated in earlier centuries, and he waged a constant combat against the unscientific fabric of the Catastrophal Theory. He taught the Uniformitarian doctrine of Hutton and Playfair. The earth, in Lyell's opinion, is the scene of never-ceasing change; but while on the one hand he refused to accept the idea of universal catastrophes, on the other he saw no direct evidence of progress and development in the history of the earth. The Uniformitarian doctrine recognises neither beginning nor end in the earth's history, and opposes just as strongly as the Catastrophal Theory the conception of a progressive evolution.

Lyell's views were welcomed with enthusiasm in Great Britain, and have there had a lasting influence upon the methods and tendencies of geological research. In Germany also, where Von Hoff had paved the way, Lyell's works attained immediate celebrity, and were made widely known by several translations. But the personal influence of Von Humboldt and Leopold von Buch was still too powerful to allow a rapid acceptance of the Uniformitarian doctrine.

France was even more reserved towards this aspect of Lyell's work. The ideas of Cuvier were deeply rooted, and were ably supported by Élie de Beaumont and Alcide d'Orbigny. It was not until after the death of these two gifted scientists that the Uniformitarians could become successful. Many of Lyell's opinions, more especially his theories regarding crystalline schists, were warmly contested, and his explanation of volcanic phenomena and mountain-making was afterwards found insufficient. At the same time, the leading principle of his geological teaching—that the key to the solution of the events of the past is to be found in the study of the natural forces still acting—has remained as the secure basis of all modern geological investigation. The recognition of this grand principle gave a new significance to dynamical geology, and brought it at once into prominence among geologists.

Sir Henry de la Beche wrote in 1835 an excellent introduction to dynamical geology, entitled *How to Observe;* in later editions, the title was changed to *The Geological Observer.* De la Beche followed essentially the same method as Lyell, and his book, which is full of new observations and facts, may almost be regarded as a supplement to Lyell's *Principles.*

A. *Geological Action of the Atmosphere.*—The destructive and constructive activity of the atmosphere plays in general but a small part in the conformation of the earth's surface, and was for a long time neglected by geologists. Chemical effects can only be produced by the atmosphere in its combination with water or living organisms. Mechanical forms of destruction are effected by the atmosphere in all regions subject to marked extremes of seasonal or diurnal temperature, the wasting of the rocks being considerably aided by the strain of alternating expansions and contractions. The geographer Livingstone was the first who observed that in the African deserts sharp fragments sprang away with a ringing tone from the basalt rock whenever a hot day was succeeded by a night with very low temperature. Other travellers have since confirmed this observation, and have ascertained that the so-called "Hammada" region undoubtedly owes its surface-mantle of angular fragments of stone to the destructive effects of rapid variations of temperature.

According to Tietze (1886), the *débris* in the sterile rainless mountain-territories of Persia is chiefly produced by the disintegrating influence of insolation. Again, in the region above the snow-line in mountain-chains, the accumulations of *débris* are attributable to the daily alternation of frost and warmth; but in most areas the strain is occasioned not so much by the rapid change of temperature as by the presence of water in the fine rock-fissures, and the pressure exerted during alternate freezing and evaporation of the water.

The geological effects of the wind are of importance. Neglecting here the disturbances caused by hurricanes, many striking phenomena have been traced to the influence of wind-borne sand or dust. As early as 1847, Naumann described polished and furrowed rocks near Hohburg, in Saxony, and erroneously ascribed the appearance to the action of ice. Heim in two papers, in 1870 and 1874, showed that the markings on the rocks had been produced by wind-swept grains of dust and sand. Similar wind scratches had been mentioned by Blake in 1855, and by Gilbert in 1874, from the western states of America. Zittel, Rolland, Walther, and others have reported how frequently one may observe wind-worn rocks in the Sahara with a polished glassy surface, dotted with cavities, or deeply scored and fluted.

Other phenomena of a more imposing nature in the great desert wastes and steppes owe their origin to the wind. In the Monument Park of Colorado, the numerous picturesque-looking rocky pillars with a narrow basis have been explained by Gilbert as remnants left by wind-weathering. The clouds of dust borne along by the wind attack chiefly the lower levels of the pillars, and reduce these so that the top-heavy upper portions are gradually undermined. Similar appearances in the Arabian desert have been described by Fraas, who called them "Fur-cap Rocks," on account of their characteristic form; Walther called them "Mushroom" rocks. More recently, "three-cornered" rocks in the dunes and steppes of Northern Europe, in the Rhone Valley, in the neighbourhood of Vienna, and other European localities, have been attributed to the work of the wind. In the Sahara, pillars or table-like eminences have been undercut by wind-borne dust and sand, and remain as "island rocks"—the so-called "gurs of the desert." Long-continued action of the wind may hollow out basin-shaped

cavities, channels, and tunnels in sand-dunes, clay, and loess deposits, and in glacier ice.

The formation of sand-dunes is due to the driving action of prevailing winds blowing over flat sea-boards and arid inland districts. Lyell, De la Beche, and Élie de Beaumont were among the earlier investigators of sand-dunes, and later authors have added much to our information on the changes of shape, the mode of travel, and the particular kinds of sand characteristic of the dunes in various localities.

The clay deposits so widely distributed in the Pampas of South America were considered by A. Bravard in 1837 to be æolian or wind-blown deposits; but Burmeister regarded them as fluviatile in origin, and Santiago Roth as partially marine and partially fluviatile in origin, afterwards altered by the growth of vegetation.

The term "loess" has been applied to yellowish clay or loam deposits, which were first described in the Rhine Valley, and have been found to be present sometimes in remarkable thickness over wide tracts of country. Baron von Richthofen found in China that these deposits attained thicknesses of 1500 to 2000 feet, and occurred locally as high as 7000 feet above sea-level. He noted the want of stratification and the uniform character of loess deposits over great distances, its constituents being invariably the finest particles of sand, clay, and limestone, no matter what the nature of the ground might be upon which the loess had gathered. He further observed its porous structure, and showed that the rootlets of grass growing on its surface gave origin to pipes similar to those which perforated the whole mass. Another important feature was the rich occurrence of remains of land molluscs, and of herbivorous and other mammals, whereas fresh-water shells were absent. Upon the evidence of those observations, Von Richthofen concluded that the loess had originated as wind-drift. And he pointed out how the dry, fine-grained material, readily transported by wind, would naturally tend to accumulate on vast steppes covered with grassy vegetation. At the same time, Von Richthofen recognised a "lake-loess" in certain localities, in the formation of which water had participated.

This explanation of Von Richthofen's was then applied to European occurrences of loess deposits, but the question seems to be one which has to be determined independently

in each locality. A number of geologists have upheld the opinion of Lyell and Agassiz that loess was of lacustrine or fluvio-glacial origin. Gümbel, in discussing the Bavarian loess deposits, drew attention more especially to the effects of intermittent inundations of land during the frequent oscillations in the retreat of the Alpine glaciers. Laspeyres, Baltzer, De Lapparent, and others think that torrential rains and other subaerial forms of water have assisted in the formation of loess.

B. *Geological Action of Water—Springs.*—Water takes undoubtedly the first and most important place amongst the epigene geological agents. Its chemical and mechanical activities are partly destructive, partly reproductive. They affect the whole surface, and have not only determined the present conformation of our planet, but have also given origin to a very considerable part of the rock-material of the Earth's crust.

The authors who have contributed most to our knowledge regarding water circulating in the ground are Bischof, Paramelle, Lersch, and Daubrée. Gustav Bischof wrote the first scientific account of springs, illustrating it with his own numerous observations on the relations of the underground water in the Rhine Valley, on the ascent of springs, on Artesian wells, and subterranean water-courses. Many of the examples cited by Bischof are now familiar in text-books of geology and physical geography. *L'Art de découvrir les Sources*, a work written by Abbé Paramelle, and translated into German by Cotta in 1856, contains excellent hints on the methods of finding springs and underground water. Paramelle was the most successful water-diviner that ever lived; France owes to him the disclosure of numerous springs. In 1864 and 1865 B. M. Lersch published at Berlin his books on the Chemistry and the Physics of Natural Waters. His *Hydro-Chemistry* gives especial attention to the therapeutic aspects; while in the *Hydrophysics* there is, in addition to his own observations, a carefully collected and accurate account of all springs previously mentioned in literature. Although the arrangement of this work leaves much to be desired, the fund of information which it contains gives it permanent value as a book of reference.

The most complete works on natural waters are those

published in 1887 by Daubrée,[1] under the titles of *Les eaux sous-terraines à l'époque actuelle*, and *Les eaux sous-terraines aux époques anciennes.* They treat in a comprehensive and scientific manner the origin, the geological occurrence, the physical and chemical properties of normal springs, underground waters, mineral and thermal springs. In an earlier work, Daubrée had described the results of his experimental researches on the permeability of different kinds of rock. The famous author was not content with a record of his own wide knowledge and experience of springs, but exhausted all geological and geographical literature on the subject, and even referred to special technical estimates and journals. In the first volume, Daubrée devoted a chapter to Artesian wells, which he classified according to the geological age of the particular water-bearing strata. He distinguished common or *normal* springs and *thermal* springs whose water moves according to hydrostatic laws, from the *underground* waters forced onward by carbonic acid and other gases, or by vapour. The second volume contains an account of the chemical composition and the temperature of springs and underground water, and this is followed by a discussion of the Earth's heat and the possible significance of the circulation and ingress of water in deep horizons of the crust as a means of inducing volcanism. The last volume treats of the geological

[1] Gabriel August Daubrée, born at Metz, studied at the Polytechnic School in Paris; began his career as a mining engineer in 1834, and was sent to England, Sweden, and Norway on a commission from the Government. As mining engineer and Professor of Mineralogy and Geology in Strasburg, he devoted his time to the geological relations of Alsace, and published in 1849 a geological map of Lower Alsace, following it in 1852 by an excellent geological description of this neighbourhood. During the years 1857-61 Daubrée was engaged in leading and collecting the springs of Plombières, and had opportunities of making important observations on the chemical action of thermal water. These were the basis of his subsequent experimental attempts to determine the geological action of superheated aqueous vapours. In 1861 he became Professor of Geology at the Museum in Paris, and displayed untiring energy in this capacity, at the same time carrying out a brilliant series of experimental researches for which his name will ever remain famous in the annals of geology. From the year 1862 Daubrée also taught mineralogy at the School of Mines, and in 1872 he was made Director of that institute. During the last twenty years of his life, he was a member of the Commission for the publication of the special geological map. Daubrée died in Paris on the 29th May 1896. He was throughout his long and active career greatly revered and loved for his amiable disposition and noble, conscientious character.

work accomplished now and in former epochs by the physical and chemical agencies of subterranean water.

Chemical Action of Water.—The importance of water as a chemical agent was early recognised, and its corrosive effects on rocks were frequently discussed in the older literature. K. G. Bischof[1] created a new scientific basis for this field of geology. With admirable mastery of the subject, Bischof set forth in his *Text-book of Chemical and Physical Geology* (1846-47) all the chemical processes which take place when meteoric water and different kinds of aqueous solutions come in contact with rocks. He also enumerated and described the minerals and rocks according to their chemical composition, structure, texture, and characteristic modes of decomposition. The new branch of geology thus outlined by Bischof attracted great interest, and soon a large number of special memoirs made their appearance. One of the best known works on mineral decomposition was published in 1886 by Sterry Hunt; it treats for the most part the appearances of decay in crystalline rocks.

Evidences of meteoric weathering of the rocks are shown in the changes of colour produced by oxidation, and in the removal of the more soluble mineral constituents of rocks. The superficial inequalities and degradation produced by sub-aerial agents are enhanced by the percolation of water through the body of the rock. Continued disintegration of the rocks gives origin to soils and coarser *débris*, and the effect of disintegration may often extend to a considerable depth below the surface, gradually rotting and loosening a whole mass of rock. The weathering caused by chemical changes alone cannot, however, be regarded as a leading factor in producing land-forms. Only the minor features of surface conformation are due to the decay of rock *in situ*. The chemical and mechanical forces of water must combine to produce the major effects in surface conformation. The rapid removal of decaying mineral matter by streams and rivers exposes fresh rock surfaces to the disintegrating chemical action of the

[1] Karl Gustav Bischof, born 1792 in Nürnberg, studied in Erlangen, and was afterwards a university tutor there. In 1819 he was made extra-Ordinary Professor of Chemistry in Bonn; in 1822 he received the full professorship, and contributed in a high degree to the fame of that university; died 30th November 1870 at Bonn.

atmosphere. The fresh surfaces in turn decompose, and the cycle of chemical transformation and denudation goes on until a land area acquires the particular aspect of erosion which the eye has learned to associate with certain characters of rock, and conditions of altitude, of meteorology, and of drainage. The final phases of the work of denudation would be to reduce a land surface to sea-level unless other circumstances conspired to prevent complete degradation of the land.

Highly characteristic forms of weathering may be produced in cases where certain portions of a sheet of rock are more soluble than others, and become a more easy prey to the processes of disintegration. Heim has described the scenic effects due to the weathering of the different kinds of rock-material exposed in many of the mountain plateaux of the Alps. Irregular, boldly-hewn outlines and sharp aiguilles are characteristic forms in the crystalline masses composed of coarse-grained granitoid rocks at the higher altitudes of the Alps; the finely-serrated ridges with steep slopes and grassy hollows are characteristic of the softer shales and clays, while the limestone and dolomite mountains present alternating terraces and prominent escarpments capped by picturesque summit forms; in some cases, wide summit-plateaux have been rendered almost impassable by the innumerable petty pinnacles and ravines into which the rock has been weathered. Such summit-plateaux are known as "Karrenfelder."

The precise origin of the "Karrenfelder" has long been a matter of discussion. Among the earlier Alpine authors, Scheuchzer and De Saussure attributed these limestone wastes to the erosive action of occasional floods. Hirzel, who in 1829 introduced the term of "Karren," attributed them to combined mechanical and chemical weathering acting upon perpendicular limestone strata at a certain height above sea-level. Among recent authors, Von Richthofen, Heim, Mojsisovics, and many others explained the jagged and channeled character of these high plateaux as in the main a chemical effect, due to the action of rain-water containing carbonic acid gas in solution, upon the lime carbonate of the rock. Favre, on the other hand, associated the particular effect with the mechanical operations of glacial water.

Mojsisovics has described characteristic "Karrenfelder" in Carniola like those in other limestone groups of the Alps, and has also observed funnel-shaped depressions on the surface of

the limestone rocks of that locality, which he attributes to the chemical effects of rain-water acting upon the surface.

These Carniola cavities must not be confused with the "dolinas" or "swallow-holes," which are of common occurrence in many limestone areas. The latter are explained as insinkings of the surface which have taken place after the subjacent mass of limestone has been undermined by subterranean caverns. Recent geological writings have shown that dolinas pre-eminently occur along natural joints and fault-planes, into which surface-water readily passes.

While dolinas, Carniola cavities, and "Karrenfelder" are forms of erosion limited to limestone mountains or table-lands whose rock is firm and compact, the so-called geological "organs" or earth-pipes (sand-pipes, sink-holes) occur chiefly in plains whose rock-material consists of soft, fissured limestone, calcareous conglomerate or gypsum. They are cylindrical or funnel-shaped cavities, generally upright in position, and filled partially or wholly by loam, mud, or sand.

Sand-pipes were first described by Brongniart and Cuvier (1811) from the neighbourhood of Paris, and were called "Puits Naturels." In 1813, Mathieu described similar pipes, narrowing towards the base, at Petersberg, near Maestricht, and he called them "Orgues géologiques," the name which is still commonly used. Other writers of that time, Gillet-Laumont and Bory, explained them as due to the solvent and mechanical action of water, infiltrating from the surface, but this idea was contested by later writers, and various erroneous explanations were offered. Lyell and Prestwich examined the earth-pipes and sack-shaped depressions in the chalk of the south of England; and they proved beyond doubt that these hollows had been eroded by the chemical action of surface water rich in carbonic acid, which had primarily found its way along any surface crack, or the fine tubular perforations formed by the root-growths of the surface vegetation. The infilling of sand and clay was derived from the surface layers and soil.

In the Bavarian plain, Penck's recent researches on the glacial and interglacial deposits have brought to light many fine examples of sand-pipes occurring in the nagelflue or rough limestone conglomerate deposits laid down by glacial floods. Penck thought the sand-pipes had been hollowed out during the period when the nagelflue presented a surface

exposed to subaerial weathering, and that some of the fine, loose clays had afterwards sunk into the erosive and pitted surface of the nagelflue rock. In many cases, however, the sand or clay in the pipes undoubtedly represents the insoluble residue left after the removal in solution of the calcareous material in the conglomerate.

Subterranean caverns always formed a subject of general interest in literature, and have given rise to many traditions and superstitions. The ancients held them to be entrances into the lower world, and the home of nymphs and fauns. In later centuries literature peopled them with all kinds of imaginery beings, fairies, dragons, dwarfs, and evil spirits, and ascribed their origin to earthquakes, inthrows of the Earth's crust, subterranean fires and floods.

Towards the close of the seventeenth century, Leibnitz gave an accurate description of the Baumann cave in the Harz district, and Valvasor examined the caves in Carniola. During the following century, although the number of accurate descriptions increased, little advance was made in the explanation of their mode and origin. Kant's *Text-book of Physical Geography* (1801) attributes the origin of caves partly to the erosion of the rock by water, partly to outbreaks of fire.

A new epoch in the literature of caves began with Esper's investigation (1770-90) of fossil remains of mammalian bones discovered in the French caves. Interest then centred in the palæontological significance of the remains in cave-deposits. Cuvier's *Recherches sur les ossements fossiles* contains an able summary of all existing knowledge on the subject of cave-remains during the first two decades of the nineteenth century. The two brothers Wagner, in Germany, and Buckland by his standard work on the *Diluvial Remains of England*, worthily followed Esper's example in collecting information and examining ossiferous caverns. The work of Schmirling, in Belgium, won well-merited fame on account of its splendid illustrations; it was descriptive of the caverns in the province of Liége (1833-34). Marcel de Serres in 1838 published his interesting *Essay on the Causes which have contributed to the Accumulation of Fossil Bones in Caves.*

There is now scarcely any difference of opinion regarding the origin of caves. A few caves occur in crystalline or clastic rocks; they are the result either of tectonic disturbances, or they represent spaces that have formed during the cooling of

volcanic magmas. The great majority of caves occur in limestone, dolomite, or gypsum deposits, and owe their origin primarily to the solvent agency of the water circulating through the ground. Water as it passes down rock-fissures attacks the sides of the rock and widens its own channel, the solvent action of the water being greater when it is surcharged with carbonic acid. Larger water-courses find their way into the widened fissures and may erode complicated systems of tunnels and grottoes like those in Carniola, where the subterranean streams act both chemically and mechanically on the neighbouring rock. The streams partially dissolve the material, partially carry it away in suspension, or leave a finely-ground, insoluble deposit on the floor of the cave known as "red earth."

The caverns may be further enlarged by collapse of the roof from time to time. Frequently surface-material, or organic remains imbedded in the deposits above, are thus introduced into limestone caverns. A stream or river-channel eroded in a limestone bed may be intercepted by the occurrence of clefts and swallow-holes, and the superficial stream may thus be guided into the system of subterranean intricacies which had been previously excavated by the chemical action of underground water.

Many caverns were undoubtedly used by the mammals of the diluvial period as shelter-places, just as they were afterwards used by primæval man. Often, however, the remains of mammals that are found imbedded in the soft clay, sand, or loam have been subsequently swept into the caves from the surface in consequence of roof collapse. During the latter half of the nineteenth century it has been a matter of controversy among the authorities on cave remains whether man was or was not a contemporary of the cave-bear, the mammoth, the woolly-haired rhinoceros, and other extinct mammals in Europe. The newest contributions to the literature of ossiferous caves deal more with their topography, physiography, and accessibility. The year 1894 was marked by the publication of two pioneer works in this particular aspect of the study of caves, the one by the Austrian writer, Franz Kraus, the other by the French writer, E. A. Martel.

The purely *mechanical* activity of running water is expressed in the removal and transportation of loosened fragments of rock (ablation), in the grinding action of the transported

material as it rubs against the floor and sides of stream and river-channels (erosion), and in the accumulation of the transported material as sediments (deposition). The strength of the processes of transportation and erosion depends on the volume and velocity, or the impulse, of the running water. The transportation power of streams and rivers is under ordinary circumstances confined within their channels, but although of limited extent it is a phenomenon apparent to every observer because of the energy of motion displayed. The washing away of rock-material by rain is much less apparent, but it is extended over far vaster tracts of country.

A great incentive was given to the scientific study of surface-forms and their causes by the brilliant work of the American investigators, Hayden, Powell, Gilbert, Dutton, and others. While they described the wonderful river erosion that had taken place in the table-lands of the western states, European travellers were making known the characteristic forms of erosion in the high and barren territories of inland Africa and Asia. There the irregularities of the surface are chiefly due to the periodic occurrence of torrential rains and the consequent sudden increase or rapid rise of mountain-streams, which rush as destructive floods over the table-lands, and retreat and diminish no less rapidly than they arose.

Earth-pillars or pyramids occur in majestic forms in some places, and offer more familiar examples of the surface-waste accomplished chiefly by rain. In miniature, the formation of an earth-pillar may be observed in any thick foliage wood after a heavy shower of rain. The drops as they fall from the leaves upon the soil sometimes alight upon small pebbles, sometimes upon soft humus. The latter is readily washed away, the pebbles remain and serve as protecting caps to the soil immediately below, so that each pebble and the underlying soil gradually stands out as an individual column. Rain-eroded pillars occurring on a grand scale in the Hautes Alpes were described in 1841 by Surell; Sir Charles Lyell described pillars in the morainic conglomerate in the Tyrol, where the larger boulders had served as capping-stones. Hayden made known magnificent examples in the conglomerate rock of Colorado. Sir Archibald Geikie described their occurrence at Fochabers, in the north-east of Scotland, in Old Red conglomerates.

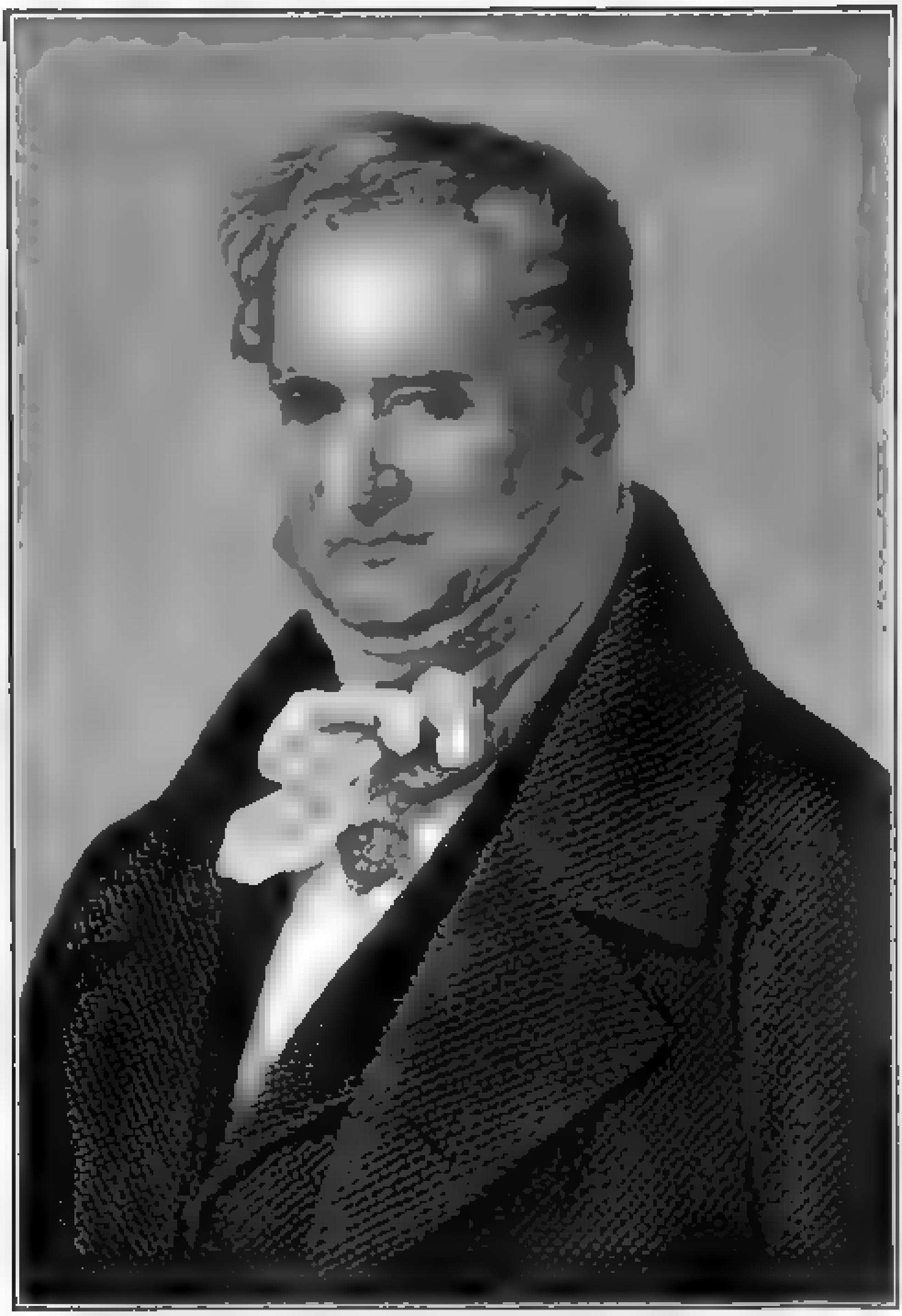
Although many writers of the eighteenth century had devoted

attention to the erosion effected by running water, their researches lacked a scientific basis. Guettard had already laid hold of the main principles of ablation and erosion when he, in 1774, set forth the "degradation" of mountains and the whole earth surface. Targioni also explained surface conformation upon true principles; while Eber was such an ardent believer in Guettard's views that he drew accurate panoramas of the Swiss Alps in order that posterity might be enabled to recognise subsequent changes in surface conformation. On the other hand, De Maillet and Buffon attributed the excavation of valleys to the action of submarine currents during the retreat of the ocean and the emergence of islands and continents. These views were afterwards upheld by Cuvier, De Saussure, and Werner, and recur in some measure in the early editions of Lyell's *Principles*.

Pallas thought the destruction of mountains and the formation of valleys was associated with intermittent local floods, and this explanation found favour with Buckland, Sedgwick (1825), Daubeny (1831), Élie de Beaumont (1829), and many others. This theory gave support to the "diluvialists," who taught that the Mosaic flood was the final and grandest event in a series of inundations, and that which had mainly shaped the present surface conformation of the globe. It is interesting to remember that Buckland introduced the term *denudation* to express the scouring and hollowing of the continents which he attributed to the action of a universal flood.

But the more natural principles inculcated by Guettard and Targioni steadily made their way as the number of geological observations increased. Hutton and Playfair, by their admirable treatment of the subject, opened up this field of research upon scientific lines. In France and England, during the early decades of the nineteenth century, Montlosier and Poulett-Scrope explained the origin of many valleys solely as a result of the erosive activity of streams, and this was the view supported by Von Hoff and Kühn in Germany. In 1829 Murchison and Lyell together wrote an essay "On the Excavation of Valleys," in which they showed their appreciation of the potency of river erosion. This explanation then came to be currently accepted; at the same time it is freely admitted that many valleys owe their primary origin to tectonic causes.

Lyell was the first to investigate the work done by erosion within a definite period of time. Upon the basis of the



ALEXANDER VON HUMBOLDT.

advance of erosion he made a calculation of the age of the Niagara Falls; his result was afterwards modified by Woodward and Gilbert. In the second half of this century, the rate of river erosion has been examined in minute detail. Physicists, geographers, and engineers have combined their efforts to obtain an accurate determination of the rate of movement in the different parts of a river-course, and the corresponding capacity of the stream to transport solid material. Geologists especially investigated the abrasive work effected by the transported pebbles and sand in deepening and widening a river-channel. In American literature, the writings that had the most marked influence upon contemporary science were Dana's publications in the *Reports of Wilkes' Exploring Expedition* and his *Manual of Geology* (1863), and Newberry's "Description of the Grand Cañon" in his *Report upon Colorado* (1861).

Oldham elucidated in 1859 the erosion of the valleys in the Khasi Hills of India, Rubidge investigated the work of water in eroding the South African valleys, and in 1870, Blanford gave an account of the Abyssinian valleys. Greenwood, Jukes, Whitaker, and Topley dealt exhaustively with the erosion of English river-valleys. In 1869, Rütimeyer published at Bâle his famous work on Valley and Lake Formation, which has exerted a permanent influence upon geological thought. Rütimeyer endeavoured to prove that the majority of the mountain-valleys in Switzerland, including the largest river-valleys, had originated only in virtue of stream erosion, but that long geological periods had been occupied in the excavation of the channels. The commencement of the valley erosion had been coeval with the uprise of the Alps, but erosion had not always progressed with the same intensity. Erosion had worked from the foot of the mountains backward and upward to higher levels, consequently the different portions of a river-course might present distinct types of erosion (waterfalls, lakes, rivers, etc.). A sketch-map illustrating the history of the lakes and rivers of Switzerland accompanied Rütimeyer's work, and was of special value as the first bold attempt to classify the Swiss valleys according to their geological age.

The American geologist Gilbert, in 1877, in his *Geology of the Henry Mountains*, established the fundamental laws of river action in the erosion of valleys. The researches of Powell and

Dutton in Colorado, and of Davis in Pennsylvania, corroborated Gilbert's results. These American geologists demonstrated conclusively the backward progress of erosion during the excavation of a valley, and the definite relation that exists between the gradient of a river-bed and the excavating force of the river. Hence the base-level of valley erosion could be ascertained with great accuracy.

Following Rütimeyer's method, W. Morris Davis depicted the different stages in the development of a valley. In its juvenile stage the rushing stream furrows narrow channels with deep banks; in its mature stages the angle of declivity is less, the valleys become broad and the banks gently sloped; in the older stage the valley-bed is worn away to the base-level of denudation. Should any crust-movement locally lower the base-level, then the cycle of valley-formation begins anew. Davis then tried to determine the geological age of various eroded plains and their drainage systems.

The publications in Europe during the last two decades of the nineteenth century are in the main based upon the principles enunciated by Rütimeyer and the American writers.

A difficult problem is presented by the transverse valleys that cut across mountains, plateaux, and sometimes across several parallel chains. The theory of origin by tectonic faults seemed especially applicable in their case, and many of the best authorities at the present day support this explanation. But Medlicott, in 1865, in the *Memoirs of the Indian Geological Survey*, pointed out that not only was the central chain of the Himalayas clearly older than the lateral Pliocene chains, since the materials of the central chain had contributed to the rocks of the lateral chains, but the Himalayan river-courses had also been defined previous to the uplift of the Pliocene chains, and had successfully continued to erode their valleys along the old lines while these chains were being slowly uplifted.

J. W. Powell expresses the same idea in more precise terms in his explanation of the course of the Green River across the Uinta Range, and of the Colorado River in its deep cutting through the Arizona plateaux. In both cases the river passes from younger strata into older; and Powell's explanation of the apparent enigma is that after the river had eroded its channel rocks were uplifted at one portion of its course, but so slow was the rate of uplift that the river was enabled to

deepen its channel either proportionately or more rapidly, so that it was never diverted from its former course.

Independently of Medlicott and Powell, Tietze arrived at a similar explanation of the origin of transverse valleys in the Elburz mountains in Persia, and of the Iron Gates of the Danube across the Transylvanian mountains. Tietze refers the beginning of such transverse valleys to a period when the chains across which they pass had no existence as such, but still formed part of a continental plain. The Swiss geologists, Heim and Brückner, support this theory, but it has been opposed by Löwl, who accepts Rütimeyer's explanation that the backward erosion of valleys may finally cut through watersheds and even entirely through mountain-chains.

Within the last few decades geographers have made great advances in the detailed knowledge regarding the erosion of river-channels, the diversion of river-courses, the serpentine windings, the recession of watersheds, and the causes of special forms of erosion such as river-terraces and pot-holes. These are fully treated in Penck's *Morphologie* (vol. i., pp. 259-385).

The first exact reports on the quality and kinds of material transported by rivers were those made by Mr. Everest (1832), who determined that the average annual amount of detritus covered by the River Ganges amounts to $\frac{1}{510}$ by weight. Under the auspices of the United States Government, a very important series of investigations were carried out on the Mississippi river. The accurate results obtained there by the engineers Humphreys and Abbot showed that the proportion of material held in suspension by the river was $\frac{1}{1500}$ by weight, and that the total weight of earthy matter annually transported to the Gulf of Mexico by the Mississippi river amounted to 812,500,000,000 pounds. (*Report upon the Physics and Hydraulics of the Mississippi*, 1861.)

Nearly all the great rivers have now undergone examination in this respect, and the results obtained have given geologists a much clearer conception of the actual rate of progress of subaerial waste. In an able essay, entitled *On Modern Denudation*, published in 1868, Sir Archibald Geikie made careful calculations of the amount of material annually transported by rivers, and showed how an irregular surface can be entirely levelled to a plain by the subaerial agencies of denudation.

A large number of interesting observations have also been made by geologists on the wear and tear that takes place on broken rock-material in the course of its transport by a river. Professor Daubrée demonstrated experimentally the effects of mutual abrasion. By subjecting fragments of granite and other rocks to artificial means of trituration and friction, he produced the rounded water-worn forms of pebbles and the fine sand and mud characteristic of river detritus. He also showed that the chemical action of the water appreciably contributed to the dissolution of the fragments. The deposition of the transported material over alluvial tracts at the entry of rivers into fresh-water lakes and the ocean, was fully and ably treated in the writings of De la Beche, Lyell, and Élie de Beaumont. And since the publication of the earlier works, the literature has been enriched by the special contributions of Delesse, as well as by the excellent exposition of the subject contained in the text-books of Geikie, De Lapparent, Von Richthofen, and others.

The speculative aspect of the invasions of the land by the sea had been frequently dealt with in the writings of the Greek and Roman philosophers. Careful historical records had also been kept of the more striking changes in the Mediterranean coast-lines. Von Hoff, in his account of the inroads made by the sea, embodied all the previously known data, both historical and scientific, regarding the mechanical action of breakers, tides, and currents in the erosion of a coast-line. New observations were added by De la Beche and Charles Lyell; and Oscar Peschel in his *Physical Geography* (1879) discussed the particular form of coastal outlines in their relation to the destructive action of breakers.

While Peschel's views of the action were based upon a supposed stationary condition of the coasts, Baron Richthofen brought new life to bear on the subject when he pointed out that the denudation of a coast may be going on contemporaneously with a movement of elevation or subsidence of the land (*China*, vol. ii., 1882). In the former case, the breakers of the retreating ocean can only erode a denudation slope parallel with the original outline of the beach, and the depredations of atmospheric weathering tend to rapidly produce an irregular appearance of the surface. As the movement ceases, a marine terrace is formed, or if several pauses occur at periodical intervals, a series of terraces is

formed. In the case of a *subsiding* coast, the effect of wave-action would be to destroy resisting cliffs and obstacles as the sea advanced inland, and thus to give origin to a submarine plain. Sir Andrew Ramsay and Mr. Davison had described in general terms the "abrasive" work of the breakers, and shown how as the level of land became degraded by subaerial forces of denudation, the margin next the sea arrived at its base-level of erosion, and sank as a denuded plain below the advancing sea. Such a plain was called by Ramsay a *plain of submarine denudation*. Von Richthofen adopted the term "abrasion," and used the expression a "plain of abrasion" to signify more particularly a submarine platform whose surface had been abraded during subsidence of the land by the destructive action of marine breakers and currents. Sir Archibald Geikie, on the other hand, thinks that submarine platforms have owed their degradation of level essentially to subaerial agents of erosion, and that they represent land surfaces which had arrived at the base level of erosion before they were submerged, the action of the waves merely completing the process of levelling. De Lapparent, Penck, and many other geologists similarly explain the origin of plains of denudation by subaerial erosion.

Recent maps of Oceanography show at a glance that submarine platforms sometimes extend for many square miles as a marginal belt around continents or islands, and geographers find it very difficult to determine the precise conditions to which these "peneplains" owe their existence in the various regions. Several German and Austrian geographers, following Richthofen's methods, have conducted special investigations on this subject during recent years (Fischer in 1885 and 1887, Krümmel 1889, Philippson 1892, Penck 1894).

The old idea, favoured by De Maillet, Buffon, Cuvier, and others, that marine currents played an important part in the configuration of the globe, has been proved fallacious. Marine currents lose their strength as they come into the shallow areas near the coast; they increase in strength where they pass through narrow channels, especially where, as in the Straits of Gibraltar and the Bosphorus, they sweep between two seas. The origin of the deeper furrows and basins in the floor of the ocean can in very few cases be explained by submarine erosion. As a rule, they represent either continental valleys that have been submerged or troughs formed by crust-movements.

Under Buckland's term of "denudation," geology at the present day signifies that process which, if continued far enough, would reduce all surface irregularities of the globe to a uniform base-level, but the general term makes no premisses about the particular agencies affecting the removal of surface material. The chief qualifying terms in common use at the present time are "subaerial," "marine," and "submarine." *Subaerial denudation* practically comprises all the natural operations by which land-areas can be lowered; it includes the action of wind, of running water, and of ice. *Marine denudation*, so far as it affects land-areas, is limited to a narrow marginal belt. *Submarine denudation* is used to signify the wearing or scouring action of the water, or any chemical processes affecting the floor of the ocean.

Hand in hand with the advance of scientific thought regarding the causes and effects of recent denudation, there developed among geologists a clearer apprehension of the evidences of denudation in the past. In the beginning of the nineteenth century, Berzelius and Hisinger had suggested that the sedimentary series (Silurian) present in West Gothland might be only remnants of a much wider sheet of deposit which had been for the most part washed away. An important step in advance was made by Sir Andrew Ramsay in his work *On the Denudation of South Wales* (1846). Ramsay showed that the Palæozoic sedimentary strata of Cornwall and South Wales were composed of fragments derived from older rock-material, that therefore this district had suffered immense loss by denudation in very early geological epochs.

Emmrich in 1873 had drawn attention to the evidences of transportation of Triassic rocks in Southern Thuringia, and in 1880 Bücking made an approximate estimate of the amount of denudation, calculated from the thickness and extent of the derived deposits. The researches of Pomel and Zittel in the Libyan Desert and the Algerian Sahara, with their numerous isolated hills, proved that this area had been denuded on a scale of remarkable magnitude, probably by subaerial agencies during the Pliocene and Diluvial periods. Dutton's famous work on the Grand Cañon showed that the extensive denudation of the Colorado lands had been likewise accomplished within comparatively recent geological epochs.

Neumayr, who made in 1885 a special investigation of the original distribution and extent of the Jurassic formation,

found many evidences leading to the conclusion that there had been enormous denudation of Jurassic deposits in certain areas. These few examples suffice to show how cautiously one must use the present disposition of geological formations as a basis for the reconstruction of maps portraying the distribution of continent and ocean in past geological epochs. It is almost impossible in the case of the older sedimentary deposits to ascertain the amount of denudation they have incurred in past ages.

Mechanical Sediments in the Ocean.—In the eighteenth century, De Maillet had investigated the deposition of sediment on the floor of the ocean. Early in the following century, the writings of De la Beche, Lyell, and Élie de Beaumont provided able chapters on sedimentation, and explained the deposition of detritus over alluvial tracts, and on the floor of fresh-water lakes, inland seas, or the ocean. The observations of these authors were made chiefly on the English, French, and Mediterranean coasts.

A classical work on the subject, *The Lithology of the Sea-Floor*, was published in 1871 by the engineer and geologist, M. Delesse. Beginning with a full exposition of the origin and constitution of the material transported from Continent to Ocean, Delesse next describes the sediments throughout the whole sea margin of France, and then depicts those in the other seas of Europe and along the coasts of North and Central America. Three coloured maps show the distribution and the petrographical character of the marine sediments in these areas, and illustrate for the first time the great variety in the nature of the deposit on one and the same coast. Delesse, applying his knowledge of the modern formations of sediments, was enabled to reproduce in cartographical form the probable distribution of land and sea in France during the Silurian, Triassic, Liassic, Eocene, and Pliocene periods. Rough sketches of a similar kind had been previously prepared by Élie de Beaumont, by Lyell and Dana. Those of Delesse have been a model for all subsequent efforts in this direction, and have never been surpassed. The Atlas by Canu, published in 1895, provides more geological detail, but the maps are less clear.

While the work of Delesse comprises all the important facts known up to the year 1871 about the constitution of littoral

sediments, it does not enter into the consideration of deep-sea deposits. The samples brought by Captain Brooke, in 1857, from the Kamtschatka Sea, at depths between 900 and 2,700 fathoms, were examined by Bailey, who demonstrated the existence of abyssal pelagic sediments composed of the shells and skeletons of Foraminifera, Radiolarians, and Diatoms. Similar deposits at smaller depths had already been proved by the researches of Ehrenberg, Joseph Hooker, and Pourtalès. In 1857, soundings were commenced in the Atlantic Ocean, when it was desired to establish cable communication between the Old and the New Worlds. Samples of the deposits of the ocean-floor were given to Huxley by Captain Dayman, and the examination of these resulted in an accurate description of Globigerina Ooze. Between 1860 and 1870 many soundings and dredgings were taken in the Atlantic Ocean, and the reports of Wyville Thomson, Carpenter, and Pourtalès added valuable scientific information about the pelagic faunas and sediments.

Oceanography was signally advanced by the results of the *Challenger* Expedition. The English ship *Challenger* sailed for four years (1872-76) on a voyage of exploration of the great ocean basins. The material brought home was investigated and reported upon by the most eminent scientific specialists of the day. The final report by Murray and Renard (London, 1891) contains an exhaustive exposition of the whole field of modern knowledge regarding pelagic deposits. A comparison of this masterly work with that of Delesse, shows what a grand accumulation of new facts had been obtained during the twenty years that had elapsed, and more especially how deep a debt of gratitude science owes to the promoters and enthusiastic workers of the *Challenger* Expedition.

In the *Challenger* Report all deep-sea deposits are classed as "terrigenous" or "pelagic" in origin (*ante*, p. 183). The former are distributed for the most part along the coast-line, upon a shallow submarine platform adjacent to the shore, and a gentle slope descending to lower depths. The pelagic deposits owe their origin partly to the organic world, partly to submarine volcanoes, and cover the floor of the open ocean. All the different kinds of sediment are described in the *Challenger* Report macroscopically, microscopically, and chemically; their exact occurrence is entered upon maps of

the soundings, and a general map is drawn representing their geographical distribution.

The deposits due to the mechanical action of water are almost entirely of terrigenous origin. River detritus and the sand and mud produced by wave action are floated seaward and spread on the floor by the action of marine currents. The blue colouring matter in terrigenous deposits is sometimes an organic substance, sometimes iron sulphide; the green colour is due to glauconite, the red colour to yellow iron ore. On the coasts where volcanic rocks predominate, marine mud consists of finely triturated volcanic material. The pelagic "Red Clay" so widely distributed in the Pacific and Indian Oceans as a rule occupies the deeper stretches of the ocean-floor. According to the investigations of Murray and Renard, deep-sea "Red Clay" is essentially composed of strongly decomposed volcanic material, originating partly from subaerial, partly from submarine eruptions, and also contains "numerous remains of whales, sharks, and other fishes, together with zeolitic crystals, manganese nodules, and minute magnetic spherules, which are believed to have a cosmic origin" (see Murray, "Oceanography," *Geographical Journal*, 1899). The Red Clay deposits pass, in most places, quite gradually into the calcareous oozes.

A special interest attaches to the chemical changes that take place in the waters of the ocean or the ocean-floor by the action of the sea-water upon the various kinds of sediment. The zeolitic, manganitic, and phosphatic contents of the Red Clay betray what an important part has been played by chemical interchange in determining the actual constitution of this extensive deposit. The more accurate knowledge of the ocean-floor has thrown a flood of new light upon all researches regarding the deposits of past geological epochs, their correlations, their origin, their constitution, their subsequent transformations, chemical and dynamical. It is not too much to say that the *Challenger* Expedition marks the grandest scientific event of the nineteenth century.

Chemical Deposits in Water.—Chemical, technical, medical, and geological works have published innumerable analyses of the chemical deposits separated in springs, underground water, rivers, and lakes. Gustav Bischof summarised the most important results of this extensive literature in his

Chemical Geology, and the later work of J. Roth (1879) contains an even fuller account of this subject. The deposits formed in a purely chemical way, without any assistance from organisms, have been so systematically and ably elucidated by Bischof and Roth, that there is now scarcely any difference of opinion among geologists regarding the origin of calcareous tufa, travertine, ochre, hydrous ferric oxide or "moorband pan," siliceous sinter, fresh-water limestone and dolomite, and other kinds of spring and fresh-water deposit. Mellard Reade has more recently calculated the amount of material held in chemical solution in rivers and transported by them to the sea. If his figures are confirmed by further analyses, they will form the basis of far-reaching conclusions.

The earliest analyses of sea-water made in the nineteenth century were those of Vogel, Marcet, Wollaston, and Bibra. In the year 1845, the famous Copenhagen chemist, Forchhammer, began a series of researches on the composition of sea-water, and twenty years later his admirable treatise on the subject was published. Bischof and Roth also investigated the composition of sea-water.

It may be said in general that no chemical deposits form on the floor of the open sea, as the immense volume of sea-water holds the substances in solution. Only very small quantities of lime carbonate and magnesium carbonate or dolomite seem to be deposited under certain conditions.

In inland salt seas, gypsum and rock-salt separate out in large quantities and form thick floor deposits—for example, in the Great Salt Lake of Utah, the salt seas of Central Asia and Southern Russia, in the Shotts of the Sahara, and in many bitter lakes. The process of the spontaneous evaporation of sea-water was studied by Usiglio (1849) on Mediterranean water, and by his laboratory experiments he determined the order in which the various salts are deposited during progressive concentration of the brine liquor. Usiglio's results were then applied in the production of salt from sea-water for commercial purposes.

An attractive account of the saline basins in the North Caspian Steppes was contributed to Erman's Journal by Baer in 1854. The salt deposits were carefully described, and the author concluded from the distribution of the basins that the Caspian Sea was formerly of far wider extent. Baer demonstrated that the waters of the Caspian Sea are still diminishing

in volume, and the salt deposits steadily accumulating in its shallow offshoot called the Karaboghaz.

Gilbert arrived at a similar conclusion with regard to the Great Salt Lake of Utah. The surface of this lake is now at a height of 4,250 feet above sea-level, but old lacustrine terraces are present at higher levels round its margins, the highest being 940 feet above the present surface-level. Gilbert explains the shrinkage in the size of the lake as a result of local meteorological changes. Owing to the diminution in the rainfall and in the volume of inflowing rivers, the surface of the lake sank below its former outlet, and the lake-water became more and more saline until it arrived at its present degree of concentration.

The most complete accounts of the Dead Sea and its salt formations are those given by O. Fraas and L. Lartet. The deposition of salt and gypsum takes place every summer, when evaporation is rapid, and a layer of mud is deposited during the intervening period of diminished evaporation.

Geologists early recognised the agreement of the chief products of super-saturation of existing sea-water and salt lakes with the layers of rock-salt in ancient geological formations of the crust. Fichtel (*ante*, p. 88) had expressed the view that the Transylvanian salt-deposits represented evaporation products formed from sea-water, which had found ingress into underground cavities after the consolidation of the crust. The upright position of salt-veins at Bex, in the Rhone Valley, led the younger Charpentier to the conclusion that the salt must have originated from sublimation in crust-fractures.

Several geologists about the middle of the nineteenth century suggested the probability of a plutonic origin of salt-layers after the manner of the massive crystalline rocks. This view was warmly repudiated by G. Bischof, who rightly argued from his knowledge of the recent deposits in the Dead Sea and the North Caspian depressions, that the salt-deposits within the earth's crust had taken origin in the same way from ancient basins of water as they became desiccated. The salt-layers of Stassfurt and Kalusz remained for a long time an unsolved problem, since no direct comparison could be found between them and any natural deposit in present course of formation. At Stassfurt, thin beds of highly deliquescent salts succeed the main salt-layer; first, a thin band of anhydrite, then a bed of deliquescent chlorides, including some sodium chloride, then a bed of potassium and magnesium sulphate, and lastly an upper

layer of double chlorides of potassium and magnesium. These salts, in spite of their high deliquescence, have been preserved from denudation in an exceptional degree owing to the presence of a thick protective surface-mantle of clay.

The subject was treated by E. Reichhardt (1866), and still more successfully by F. Bischof (1875), upon the recognised principles of desiccation.

Ochsenius in 1875 set forth the nature of the conditions under which the Stassfurt succession might have been formed in nature. He supposes a bay or a sea-basin connected with the main ocean only by a narrow channel, which was periodically closed by crust-movements, or by the accumulation of sandbanks or submarine bars which could be surmounted only at the highest tides. During the period of closure, wherever the evaporation exceeded the inflow of fresh water, a concentration of the salt water would take place, and gypsum, anhydrite, and salt would be thrown down. If a permanent isolation were finally effected, and desiccation brought about in this natural salt-pan, it followed that the salt of the mother-liquor must separate out completely in accordance with the order of their solubility.

C. *Geological Effects of Ice.*—The importance of ice as a geological agent was much later in being recognised than that of water, and this is readily explicable from the more limited occurrence of ice and the less striking character of its action. Moreover, the regions where ice displays its grandest effects were still avoided in the eighteenth century, and were only familiar to a few bold explorers. The river and lake ice of the continents, and the ocean ice of the Polar districts have little interest for geologists, since they cannot help much in elucidating the work of ice in the past epochs of the earth's history. Greater interest attaches to the glaciers of the mountain-systems and the inland ice-sheets of the Polar continental areas.

Glaciers are mentioned for the first time in literature as a subject of scientific investigation in Scheuchzer's *Reisebeschreibung der Schweizer Alpen.* The indefatigable and learned scientist records the few observations of Simler and Hottinger on the origin and movement of glaciers, and after a careful description of several glaciers visited by himself, he explains the movement as a result of the infiltration and

freezing of water in cracks and other spaces. Scheuchzer is thus the founder of the Theory of Dilatation, afterwards advocated by Charpentier and Agassiz. The pastor Altmann in 1750, and Gruner in 1760, wrote about glaciers without bringing forward anything essentially new. They referred the movement of Alpine glaciers to the sliding of the ice on a sloping base. Neither Scheuchzer nor the two last-named authors had given special attention to the moraines.

A short paper, published in 1787, by Kuhn in Höpfner's *Magazin für Helvetiens Naturkunde*, contained not only an excellent description of the Grindelwald glacier and its moraines, but the author also followed the old moraines, and concluded that the glacier had formerly been of far greater extent. De Saussure's famous *Book of Travels* (1796-1803) contained accurate descriptions of the glaciers in Wallis, the Bernese Oberland, and the Mont Blanc group. The form, arrangement, composition, and movement of the moraines were all carefully handled. Saussure also used the moraines as a means of determining the extent and the advance and retreat of the glaciers, without, however, drawing any general conclusions. Strange to say, he associated neither the smoothness of the glacier floor nor the "Roches moutonnées" with the movement of ice-masses.

Saussure had in F. G. Hugi a successor who accomplished much for the knowledge of Alpine glaciers. A fearless mountaineer, Hugi explored the upper reaches of the glaciers; in 1827 he even built a hut on the Finsteraar glacier for his convenience in carrying on researches. He observed many facts about the structure and constitution of the snow, firm, and ice at different heights, about the position of the firm line, about fissures and crevasses which had escaped previous investigators.

In the year 1821, at the Eighth Annual Congress of the Swiss Society of Scientists, the engineer Venetz read a paper on the variations of temperature in the Swiss Alps, which contained wholly new conceptions. This important paper was not published until 1833. Venetz called attention to the fact that there were not only moraines connected with the advances and retreats of the Alpine glaciers, but that in addition to those, morainic walls occurred at a greater distance from the present glaciers, and they gave evidence of glaciation on a scale of enormous magnitude in some former period. In 1829 Venetz

gave confirmatory evidence in favour of the much grander dimensions of the Alpine glaciers in a past age. In addition to the morainic walls he referred to ice transport of the erratic boulders dispersed in such numbers in Alpine valleys and across the plains at the base of the Alps, and throughout Northern Europe.

Under the influence of Venetz, Charpentier (*ante*, p. 103), director of salt-works and a personal friend of Venetz, became deeply interested in glacial studies. Starting with the idea that his friend had formed erroneous conceptions, Charpentier soon became a convert, and declared himself openly in their favour. He gave in 1834 a memorable address at Lucerne, in which he showed that the large erratic blocks could not have been transported by water; that the frequent scratches and deep grooves on the rocks in Wallis are the work of glaciers; that the occurrence of morainic walls and erratic blocks remote from the present glaciers proved incontestably the former presence of longer, wider ice-rivers. He thought the greater glaciation of the Alps in a former epoch might be explained by the greater height which the Alpine summits had once attained.

Enthusiasm for the subject was now thoroughly aroused in Switzerland. Acting on the initiative of Charpentier, and under his personal guidance, Louis Agassiz, in the summer of 1836, made his first glacial studies at Bex on the erratics in the Rhone Valley, and explored the glaciers of Diablerets and in the neighbourhood of Chamonix. His fellow-student and friend, Karl Schimper, accompanied Agassiz on most of these excursions. The genial Munich botanist had already made a study of the erratics on the Bavarian plain at the base of the Alps, and had explained them as masses transported from the mountains by floating icebergs.

Schimper, from numerous observations on the variation of past floras and faunas, formulated his conception of alternating epochs of desolation and re-animation. He identified the youngest period of desolation as that during which the erratics had been distributed, and regarded it as a great Ice Age. Schimper embodied these ideas in courses of lectures delivered in Munich to a small circle of friends. In the winter of 1836-37, Agassiz also gave a course of lectures at Neuchâtel on glaciers and the Ice Age, and copies of an ode written by Schimper on the Ice Age were distributed by the poet

himself to the members of Agassiz' class. In that poem, which was re-published in 1841, the epoch of ice was thus depicted:—

> "Ice of the Past! of an Age when Frost
> In its stern clasp held the lands of the South,
> Dressed with its mantle of desolate white
> Mountains and forests, fair valleys and lakes!"

In July 1837, Agassiz[1] laid a report of his glacier studies before the Annual Congress of Swiss Scientists, in which he expressed his view that a strong fall of temperature had taken

[1] Louis Jean Rudolph Agassiz, the son of a Swiss Protestant pastor, was born 28th May 1807 at Motiers, on the Murten Lake (Canton Waadt). He was educated first at the academy of Lausanne, and later studied Medicine and the Natural Sciences at Zürich, Heidelberg, and Munich. While still a student he occupied himself with the study of recent and fossil fishes, and after the publication of the first part of his great work on *Fossil Fishes* he came into personal relations with Cuvier and Humboldt in Paris. In 1832 the already world-renowned young naturalist was appointed Professor at the Academy of Neuchâtel, and made it an active centre of scientific investigation. In 1834 he paid a visit to England for the purpose of studying the British fossil fishes, and in the same year received from the Geological Society the Wollaston medal. In the summer of 1836 he began his glacial studies under Charpentier's direction, and pursued them for ten years with striking success in the Swiss Alps, in Great Britain, and afterwards in North and South America. In 1846 he crossed the Atlantic and delivered courses of lectures in various towns, and was appointed Professor of Zoology and Geology in the University of Cambridge, U.S.A., in 1847. He went as Professor of Comparative Anatomy to Charleston in 1851, but returned in 1853 to Cambridge. In 1859, he founded there, with pecuniary aid from private individuals and also from the State, the fine Museum of Comparative Zoology. His public lectures, also the instruction he gave at Harvard College, his numerous publications, exhibited such an almost unique activity as to procure him great popularity. His interest in his magnificent Museum, the opportunities to follow his zoological studies, and to take part in various marine expeditions which his residence near the sea procured him, and, not least, the enthusiastic reception which he had received in North America, and the influence he could have there on the whole development of scientific life, induced Agassiz to refuse many tempting offers to return to his native land, and also the offer of an appointment in Paris as a Professor in the Museum. He became a naturalised American, and died in Cambridge, Mass., on the 14th December 1873. Besides his epoch-making work on fossil fishes and his glacial studies, Agassiz published valuable monographs on fossil and recent Echinids and Molluscs, and numerous zoological works. In 1868 a report on his journey to Brazil appeared, and was followed in 1871 by another on a deep-sea investigation between Cape Horn and California. To the last Agassiz combated Darwin's theory of evolution.

place *previous* to the upheaval of the Alps; enormous masses of ice had been formed and had extended over the surface as far as erratic blocks and the scratched and polished rocks could now be observed.

Schimper took umbrage that the priority of the Ice Age Theory should, in his opinion, have been stolen from him by Agassiz, and the friendship of the two Alpinists was broken. Schimper afterwards confined himself to the publication of his Ode and of a scientific communication, which he made to the Annual Congress when it met in Neuenburg. Agassiz, however, continued the researches with unabating zeal; in company with Desor and Studer, he visited the glaciers of the Bernese Oberland, the Mont Blanc group and the Monte Rosa group, and published the results of his investigation in 1840, in a work written in French, and immediately translated into German by Carl Vogt.

This work, which Agassiz suitably dedicated to the founders of modern glacial research in Switzerland, Venetz and Charpentier, contains the first general exposition of glacial phenomena in the Alps. For much of his information Agassiz relies upon Saussure and Hugi, but he devotes far closer attention to the moraines and introduces the terminology now in common use (end moraines, lateral moraines, median moraines).

Agassiz explains the formation of median moraines through the junction of two lateral moraines, but, like previous authors, he fails to appreciate the existence of ground-moraine, although he clearly explains the etching action of sand-grains on the rocks at the bottom of the glacier. With respect to the formation of glaciers from descending firn, Agassiz agrees with the conclusions previously arrived at by Scheuchzer, Saussure, and Hugi. He regards Scheuchzer's infiltration and dilatation theory as the best explanation of glacier movement.

Agassiz recognises the great merit of Charpentier in having drawn attention to the scouring, furrowing, and polishing of rocks effected by glaciers, and strongly emphasises the work of denudation effected by glaciers on the rocky floor over which they move. He describes the hummocky bosses of rock exposed to view on the retreat of a glacier, and notes their characteristic striated appearance, and the parallelism of the striæ and grooves on their surface, with the direction that had been followed by the glacier.

Agassiz can see no sufficient evidence of any periodic regularity in the advance and retreat of glaciers; the variations of the glaciers represent, in his opinion, the result of two opposing forces—the forward movement of the ice-masses and the solvent action of the atmosphere. The precise dimensions of a glacier are, he writes, essentially correlated with climatic conditions; a change of climate produces a corresponding increase or diminution in the size of a glacier. Agassiz regards the testimony in Switzerland as absolutely convincing, that the Swiss Alps were formerly almost wholly under ice. He contributes a wealth of observations on old moraines, rows of blocks left in Alpine valleys, rock-scratches, scarred limestone wastes, pot-holes (*Gletschermühle*), and the erratics (*Findlinge*) irregularly scattered on the plain. A very valuable account was given by Agassiz of the original home, the course of travel, and the ultimate position assumed by many of the famous "erratic" blocks in Switzerland.

Not the least interesting portion of the work is that in which Agassiz disposes of various erroneous explanations previously given for "erratics" by geologists of authority—the suggestion of De Saussure and Von Buch that the erratics had been transported by river-floods, the explosion theory of Silberschlag and De Luc, the gliding theory of Dolomieu, and the drift theory of Lyell.

After brief reference to the observations of rock-scratches and erratics made by Sir James Hall in Scotland, by Brongniart and by Nils Sefström in Scandinavia, Agassiz proceeds to enunciate his theory of the Ice Age. In conformity with Cuvier's Catastrophal Theory, he supposes that at the close of the accumulation of the geological formations there took place repeated falls of temperature, and that immediately *before* the Alpine upheaval the earth became covered with a thick crust of ice. An enormous ice-sheet extended over the greater part of Europe and across the Mediterranean as far south as the Atlas mountains, over Northern Asia and Northern America; above the ice-sheet only the highest summits emerged.

While the Alps were being upheaved, the icy crust still mantled the rocks, and any fragments dismembered from the solid rock during the movements fell upon the ice and were carried away upon its surface. After the completion of Alpine uprise the climate became milder, and as the ice melted, great

and small crust depressions were exposed where the rocks had offered least resistance to the overlying weight of ice, while large angular blocks were often left in undisturbed position upon the ground-layer of pebble and sand over which the ice-sheet had previously moved.

A very short time after the appearance of Agassiz' work, Canon Rendu, afterwards Bishop of Anneçy, wrote a paper on the physics of glacier ice. He attributed to glacier ice, in spite of its hard and brittle character, a certain ductility which enabled it to mould itself like plastic clay to its surroundings. In this conception Rendu was much in advance of his time, as no observer had thought of any possible connection between plasticity and brittleness.

In the same year, 1841, Charpentier published his *Essai sur les Glaciers,* one of the grandest contributions to the geology of his time. This gifted pupil of Werner, whose pioneer researches in the Pyrenees have already been mentioned, describes in the first part of the essay the phenomena of glaciers with a fine precision, rivalling that of Saussure, and with a completeness far beyond any previous contribution on glaciers. He relies almost exclusively upon his own observations, whereas Agassiz frequently used the accounts in the literature. The second part of the essay is even more important. In it erratic blocks are discussed, and the author brings forward a convincing series of facts, from which he draws his conclusion that only glaciers could have transported the blocks and stranded them in their present positions.

With characteristic modesty, Charpentier claims neither for Venetz nor for himself the authorship of the idea that larger glaciers had formerly filled the Alpine valleys and had left the erratics strewn along them. He relates that uneducated mountaineers, more especially a chamois-hunter, Perraudin, from Lourtier, and a native of Chamonix, Marie Deville, had formed this idea and communicated it orally. He also recalls a remark of Playfair's that had long sunk into oblivion, but was the same in effect as Charpentier's own conclusion.

The hypothesis of a connected ice-sheet, which had been propounded by Agassiz, was not accepted by Charpentier. In the essay, Charpentier explains his arguments against it, and he further insists that the maximum advance of the glaciers occurred *after the upheaval and partial subaerial denudation*

of the Alps, and not before the upheaval, as Agassiz had assumed. The particular distribution of the transported blocks upon the slopes of the valleys, often in long lines, affords, in Charpentier's opinion, clear proof that river-valleys had already been eroded in the mountain-system before the glaciers made their descent to the plain. Neither does he agree with Agassiz that the Ice Age was the result of a universal fall of temperature over the earth associated with astronomical causes, but regards the climatic variations in the Alps, and the advance and greater dimensions of the glaciers, as local phenomena.

Although Agassiz and Charpentier differed in their general conclusions, both followed the true inductive method, and the leading principles which they established by their study of the Swiss glaciers have held their place in geological literature. The moraines and appearances produced by them had been treated by Agassiz with the fullest detail and the most brilliant results. But between 1840 and 1845 the glaciers themselves were made the chief subject of his investigation.

Provided with physical instruments and a boring apparatus, he went in 1840 to the Grimsel Hospice; on the median moraines of the Lower Aar Glacier he erected a primitive hut, the "Hôtel des Neuchâtelois," which he occupied together with his companions, E. Desor, C. Vogt, F. von Pourtalès, C. Nicolet, and H. de Coulon. Agassiz and Pourtalès undertook the meteorological observations and the investigations on the inner structure and movement of the glaciers. Vogt studied the microscopical fauna of the red snow, Nicolet the flora of the neighbourhood, Desor and Coulon the glacier appearances and the moraines. In the following years, Escher von der Linth, the Scotsman J. D. Forbes, the artist Burckhardt, and others, took part for a time in the work on the Aar glacier, and in the ascents of the Jungfrau, which were made under the care of the guide Leuthold.

The researches made from the hut were the first systematic observations on the movement of ice in the different parts of a glacier under the various diurnal and seasonal conditions, and on the temperature of the ice at different seasons, while the first facts regarding the thickness and internal structure of the ice were secured by means of borings.

While Agassiz and his band of enthusiastic workers were busy in the high levels, the lower valleys at the north and

south base of the Alps were being examined by A. Guyot. Agassiz had asked him to study the former extent of the glaciers and the erratic blocks. The original intention was to publish a work in common which should comprise the results of all the participants in the glacier researches; Agassiz was to write the first volume on the glacier phenomena proper, Guyot was to write the second volume on the erratic blocks in the Alps, and Desor was to contribute a third volume on extra-Alpine material. Only the first volume was ever published, Agassiz' *Système Glaciaire*, 1847, with three maps and nine folio plates. Guyot went to Princeton, in North America, and placed his 5000 samples of erratic blocks in the Museum there. The most important results of his researches were published, 1843-47, in the *Bulletin de la Société des Sc. nat. de Neuchâtel.*

When Agassiz had, in 1840, made known his Ice Age theory, he knew the Northern Diluvium only from the literature. A visit to the Glasgow Meeting of the British Association in 1840 afforded him the opportunity of studying the erratics in the Scottish Highlands. Together with his former opponent, Buckland, whom he completely converted to his views, Agassiz found signs of glacier action widely distributed, old moraines, glacier scratches, roches moutonnées, and he identified in the Scottish "Till" (boulder-clay, ground-moraine) scratched pebbles and the fine clay and sand material which glaciers push forward on the ground as they move. The importance of the scratched pebbles as indications of glacial formations was thus recognised for the first time.

In his *Glacial System*, Agassiz moderated his views on a connected polar ice-mantle over the greater part of Europe; he allowed that the glaciation of the Alps had been distinct from that of the northern lands, and that it had taken place after, and not before the upheaval of the mountain-system. He also accepted the testimony of Rendu and Forbes on the plasticity of glacier-ice, and referred the movement of glaciers to a combination of physical causes of which dilatation was only one.

The enthusiasm of the Neuchâtel glacialists was infective, and for some years glacial studies were highly popular. The physicist, James Forbes, from Edinburgh, went for three summers in succession, 1842-44, to Switzerland to study the movement of glaciers. His results appeared from time to

time in the form of letters in the *Edinburgh New Philosophical Journal.* He established the important fact that glaciers move more rapidly in the middle than at the sides and bottom, and argued from this differential motion that the glacier ice behaved like a slightly viscous mass, which under the influence of gravity was bound to flow slowly downward after the manner of a lava stream. So many of the glacier phenomena were explained by Forbes's theory of the plasticity of the ice, that it immediately found wide acceptance.

The Swiss botanist, Martins, explored glaciers in Spitzbergen and Scandinavia. He demonstrated the former greater extent of the glaciers in those territories, and made the first detailed study of "ground-moraines," and the kind of sediment deposited by the river out-flows from glaciers (glacial diluvium).

In all countries where science was cultivated rapid studies were made between 1840 and 1850 in glacial geology; Great Britain, the Pyrenees, the Black Forest, Upper Italy, Scandinavia, North America, were diligently and successfully searched for evidences of an epoch of extensive glaciation. Germany was much longer in accepting the new teaching. Leopold von Buch strongly opposed the results attained by the Swiss glacialists, and his influence retarded scientific inquiry of the question in North Germany.

The city of Munich enjoys exceptional natural advantages of position for glacial research, seeing that the Bavarian plain upon which it stands has been smoothed and scratched by the ancient glaciers upon the Bavarian Alps and the Tyrol, and the river Isar, which flows through Munich, gives immediate access to the system of Alpine valleys formerly occupied by these glaciers. The famous astronomer, Gruithuisen, had published at Munich, in 1809, a paper on the erratic blocks of the South Bavarian plain, wherein he stated that they had been brought from the neighbouring Tyrolese and Bavarian Alps. He advanced the idea that glaciers had transported them to the low Alpine levels, and then the ice-masses in which the erratics were wedged had been borne northward across the plains by enormous floods, the same which had spread the nagelflue conglomerates over the sub-Alpine Bavarian plain. As the ice-masses melted, the erratics were left in their various positions. This was in substance the conception adopted by Karl Schimper several decades later.

The North German School of Diluvial geologists looked with a certain favour upon this explanation, but believed still more in the efficacy of water action. The Berlin physicist, Wrede, in 1802 gave his opinion that the granite "foundling blocks" on the German plain had been brought upon ice-floes from the Silesian mountains. Leopold von Buch in 1810, and one or two later authors, proved, however, that Scandinavia had been the original home of most of the North German erratics; they assumed that gigantic floods had been the chief agent of transport, and that the scratches on the rocks and pebbles had been caused by the friction of the sand, pebbles, and larger fragments during transportation.

Bernhardi, Professor in the Academy of Forestry in Dreissigacker, without any knowledge of the researches of Venetz and Charpentier, by his own insight arrived at the true solution of the problem (*Neues Jahrb. für Miner.*, 1832). He said the polar ice had extended to the southmost edge of the German plain now bestrewn with erratics, and that in the course of thousands of years the polar ice had gradually withdrawn to its present reduced dimensions and more limited fields of glaciation. Before Bernhardi, the Norwegian geologist, Jens Esmarch, in 1824 had suggested there had been a far greater extension of the Norwegian glaciers than now existed. But the tide of influence and authority in Germany at the time ran in other directions; an Esmarch or a Bernhardi might say what they thought, but there the matter ended; none listened while a Von Buch and a Sefström said differently. The Swede, Nils G. Sefström, was the most extrème of the diluvialists. He taught that the northern floods had spread diluvium over Scandinavia, Finland, Russia, and Germany, and borne fragmented rock-material and big boulders from the northern areas as far south as the foot of the Alps.

During the years 1839-43, a brilliant group of British geologists, Lyell, De la Beche, Darwin, and Murchison, thoroughly acquainted with the results of the polar explorations made by Parry, Scoresby, and Ross, founded the "Drift Theory," which appeared to be a satisfactory explanation of all the phenomena. They attributed the transport of erratics and the formation of the thick surface deposits or "boulder formations," known under various local terms in Great Britain, most commonly as "till," or "boulder-clay," to floating icebergs which had drifted far southward from Polar regions. The

term "Drift" then came to be applied to the same deposits which had been previously termed "Diluvium" (*ante*, p. 114); and both terms are retained in popular use as synonyms of the more technical term "Pleistocene," introduced by Sir Charles Lyell.

A young Russian geologist, Böthlingk, published in 1839 a paper of exceptional interest descriptive of the "diluvial or Pleistocene deposits" in Finland and Lapland. In his opinion, the greater mass of the "diluvium" had virtually been deposited by floods, but the erratic blocks could only have been transported by ice. His work helped to bring the "Drift Theory" into favour on the Continent, and comparatively few of the leading geologists in Europe at that time lent a willing ear to the ice theory of Swiss geologists and their conception of a continuous ice-sheet, or glaciers hundreds of miles long.

The departure of Agassiz for North America in 1847 took away from Europe the best-known and most powerful exponent of glaciation, and a period of stagnation ensued in glacial geology.

Seven years passed, and another enthusiastic glacialist took the place of Agassiz in European literature. Sir Andrew Ramsay[1] not only proved the former glaciation of Scotland and Wales, but recognised traces of two Ice Ages in the constitution of the breccias and pebble-beds of Malvern and Abberley. He also found evidence of glacier action in the Permian period, and this raised anew the questions of climatic periodicity and ice erosion. Venetz and Morlot had been of opinion that during the diluvial epoch all the greater areas of

[1] Andrew Crombie Ramsay, born 1814, in Glasgow, was intended for a merchant's career, when, on the publication in 1841 of his excellent treatise on the geological formation of the island of Arran, De la Beche secured him as assistant for the geological survey, with which Department he was connected for forty years, first as survey geologist, then as local director, and, after Murchison's death in 1871, as General Director. At the same time he discharged his duties as Professor of Geology at the School of Mines in London. Ramsay was ranked as the best field geologist in Great Britain. His principal work is a geological description of North Wales, which appeared in two editions (1866, 1881). He also published a geological map of England and Wales, 1859; fifth edition, 1881. Besides his official duties, Ramsay occupied himself much with the problems of physical geography and dynamical geology. His *Text-book of the Physical Geology and Geography of Great Britain* appeared in five editions between 1864 and 1878. (Comp. Sir Arch. Geikie, *Memoir of Sir Andrew Crombie Ramsay*, London, 1895.)

glaciation had been repeatedly covered by ice. This view now received more credence, especially after Oswald Heer's researches on the palæontology of the Ice Age in Switzerland discovered the presence of "Interglacial" deposits containing the fauna and flora of a warm, temperate climate, and therefore betokening a prolonged interruption of the polar conditions.

After Ramsay's brilliant work had proved that almost the whole of Great Britain had been covered by a vast ice-sheet, Kjerulf and Otto Torell demonstrated that Scandinavia had been entirely buried under an ice-sheet some 6000 or 7000 feet thick. In South Bavaria, topographical conditions led Captain Stark to suggest that the surface of the plain had been glaciated; and Zittel in 1874, by his discovery of good examples of striated rocks and his determination of typical end and ground moraines, established upon a scientific basis that a great portion of the Bavarian plain had been an ice-field.

Still, however, the North German geologists held fast to the drift theory of the earlier decades of the century. It is in the memory of many living geologists how that theory received its death-blow in Berlin on the 3rd November 1875. On that evening, at a crowded meeting of the German Geological Society, Otto Torell delivered a powerful address on the course of glacier ice from the central ice-sheet of the Scandinavian plateau to the plains and basins of Northern Europe, and brought home to his Berlin audience with irresistible arguments that the erratics on the North German plain had been dispersed there by glaciers moving southward. The deep impression made by the eloquent Norwegian was never forgotten; the drift theory collapsed, and the name of Bernhardi was recovered from oblivion to receive belated honour and be ranked as that of an anticipator of glacial geology.

The German geological literature was then rapidly enriched by papers on glacial deposits. One of the most effective was contributed by Professor Penck upon the boulder-clay formation of North Germany (*Zeitschrift d. D. G. Ges.*, 1879). Since then active researches have been continued by the Prussian Geological Survey Department, and it has been shown that there are two distinct series of glacial boulder-clay, separated by interglacial layers containing remains of a rich vegetation.

Professor Penck in 1882 published a work entitled *The*

Glaciation of the German Alps, which has become a classic in the literature. The careful inquiries conducted by Alphonse Favre and Desor, and the more recent works of Heim, Du Pasquier, and Brückner, meantime advanced the knowledge of topographical and geological phenomena due to the glaciation of the Swiss Alps, while similar studies have been carried on by many eminent geologists in the countries of Northern Europe. In Great Britain, Sir Henry Howorth, Professor Hull, and Professor Bonney still support Lyell's "drift theory"; the majority of British geologists, however, have accepted the ice theory, of which Sir Andrew Ramsay, Sir Archibald Geikie, and Professor James Geikie have been the ablest exponents.

The exploration of existing masses of inland ice and of the glaciers in the high mountain-systems exerted a stronger fascination for many than the study of the deposits of the past Ice Age. Dr. Simony, a Viennese enthusiast, has taken accurate observations for more than forty years on the Dachstein glacier, and Pfaff has studied the glaciers of the Gross Glockner, in the Austrian Alps; in Switzerland, a scientific society has been founded for the pursuit of glacier research, and measurements on the Rhone glacier have been taken for many years.

Amund Helland's observations on the comparatively rapid movement of the glaciers at Jacobshavn surprised European scientists, whose ideas of glaciers had been formed mainly on the basis of Alpine glaciers. Nordenskiöld's travels, Fridtjof Nansen's bold crossing of the Greenland ice, Keilhack's and Von Drygalski's careful physical and mathematical geological observations on the glaciers and ice-fields of Iceland and Greenland, confirmed with irrefutable data the action of inland ice-masses and the correctness of Torell's explanation of the "diluvial" phenomena in Northern Europe. The boldness, the enthusiasm, and the achievements of these explorers have worked inspiringly on the public mind, and awakened an interest in the scientific aspects of Arctic territories which finds an outlet in the warm support given to the geographical societies in all countries and to the schemes for further exploration that are from time to time initiated.

As has been said, Charpentier recognised the work of denudation affected by glaciers, but much broader views of the erosive power of ice were formulated by Gabriel de Mortillet in several papers published between the years 1858 and 1862.

Ramsay then wrote a general paper "On the Glacial Origin of certain Lakes in Switzerland, the Black Forest, Great Britain, Sweden, North America, and elsewhere" (*Q. Jour. Geol. Soc.*, 1862). In this paper Ramsay attributed the excavation of many lakes and fiords to the erosive force of moving ice, and Tyndall in the same year gave his opinion that the Alpine valleys had been excavated by the same agency.

During the forty years that have elapsed since that time the erosive force of ice has been a subject of animated discussion, and still there are two distinct parties amongst glacialists, those who oppose and those who support the main issues of Ramsay's discourses. Amongst the supporters or extreme glacialists may be counted in Great Britain such geologists of authority as Sir Archibald Geikie and Professor James Geikie; in Austria, the geographer and geologist, Professor Penck; in Switzerland, Professor Brückner; in Scandinavia, Professor Nansen; while in North America Sir William Logan was a warm supporter.

Geologists who oppose the extreme view of glacial erosion have pointed out that a variety of local causes may give origin to lakes and fiords. Actual cases have been cited where fluviatile, or morainic accumulations, or crust movements would sufficiently explain the form of the basins attributed to ice erosion.

Much has been written in physics upon the causes of ice movement. Of great importance were the experiments made by Carnot and James Thomson (1849) on the liquefaction of ice under strong pressure, and the lowering of the melting point below 0°, as well as the discovery made by Faraday (1850) of the re-union or regelation of fragments of ice with moist surfaces. Application of the principle of fragmentation and regelation to the phenomena of glaciers was made by the leading physicists of the day, Tyndall (1857), Helmholtz (1865), and Lord Kelvin, and thus a scientific explanation was secured for the theory of glacier motion which had been originally advanced by Rendu and Forbes. Professor Heim, in his excellent *Handbook of Glacier Phenomena* (1885), summarises the whole field of knowledge of Alpine glaciers. He decides the question of glacier motion in the main in favour of Forbes's theory of plasticity, but he also recognises a gliding movement of the whole mass under the influence of gravity.

Numerous observations in different areas have testified to the frequent oscillations of the glaciers during the Ice Age. The glaciers appeared to have frequently retired, and ice-fields to have diminished in size as often as any amelioration in climatic conditions set in. Such variations may be observed in ice-clad regions at the present day. And as the liquefaction of the ice-masses gives rise to larger volumes of water, the frequent local floods, of which evidences are afforded in the intercalation of fluvio-glacial deposits within the glacial series, are thought to have been associated with periodic oscillations.

Two main advances of the mountain glaciers and of inland ice were determined by Ramsay for the British Isles and by Heer for the Alps, and have been confirmed by Scandinavian and German geologists upon the evidence of the glacial and fluvio-glacial deposits in their respective countries. In all these areas a prolonged interlude of milder climatic conditions appears to have intervened between two chief epochs of glaciation. But Professor Penck in recent papers has augmented the number of distinct epochs of glaciation in the Alps and North Germany to three or four, thus approaching the "five" glacial intervals enumerated by Professor James Geikie, and the "seven" by James Croll. On the other hand, Holst in Norway, Upham and Wright in North America, and many other authorities recognise only one Ice Age, marked by occasional seasonal or periodic variations of no great significance in the dimensions of the glaciers and inland ice.

It is still more doubtful whether geologists have been right in supposing that several Ice Ages occurred during geological epochs previous to the Diluvial Age. Ramsay, in 1855, explained certain Permian conglomerates in England as accumulations transported by glacial action, and Dr. Blanford applied a similar explanation in 1856 to the "Talchir" conglomerates of almost the same geological age in Central and Southern India. It then became commonly accepted that extensive glaciation had occurred in the Permian geological epoch. Erratics and scratched pebbles have since been described from the Silurian rocks in the southern counties of Scotland by Moore and James Geikie, and also in the Old Red Sandstones or Devonian rocks of Scotland by Ramsay.

The Miocene conglomerates in the neighbourhood of Turin were explained by Ramsay, Lyell, and Gastaldi as material

transported by ice, and a similar explanation was suggested for the exotic blocks in the Alpine and Carpathian "Flysch" formation. From time to time examples of boulder and conglomerate deposits were reported and were dealt with in this way. To mention a few examples: in 1870 Sutherland described breccias with polished blocks in the Karroo Beds of South Africa, and in his explanation of them as glacial in origin he was supported by Griesbach (1871) and Stapff (1899); in Australia, R. D. Oldham explained boulder conglomerates in Carboniferous and Permian time as material transported and stranded by icebergs; Waagen (1887) described scratched pebbles and polished blocks from the Salt Range in the Punjab, and referred them to a Carboniferous Ice Age; Nötling more recently (1896) concludes they belong to a Permian Ice Age; Sir A. Geikie mentioned glacial traces in the Cambrian rocks of Scotland, and Reusch (1891) in the Cambrian deposits of Northern Norway. The conclusion drawn by James Geikie and James Croll is that all the greater epochs in the history of the earth have been marked by a series of glacial and interglacial episodes.

But the number of geologists who accept the teaching of repeated glaciation of wide territories is rather decreasing than increasing. The minute detail in which geological maps are now being prepared tends to show that in many cases all these phenomena of scratched pebbles, and boulders, and polished surfaces may be observed in the sheared and brecciated rock-material occurring along the planes of great crust-movements. And in no case will a cautious geologist be willing to accept an ice age, or even local glacial action, in a remote geological epoch as the explanation of scratched pebbles and the occurrence of exotic boulders, unless he be in a position to investigate the matter for himself, or it can be conclusively proved to him that there has been no history of crust-disturbance. The attitude of present-day geology with respect to the much vexed questions of glacial action is to hold an open mind towards each alleged example.

The Pleistocene ice-mantle had its chief distribution in the north-west of Europe and in the north-east of America; but, with the exception of those large areas covered by inland ice, the evidence of glaciers is found only in mountain ranges which still possess glaciers, or in which a very slight climatic depression would call forth glaciers. Hence the glaciation

during the Pleistocene Age is most simply regarded as representing an extreme phase of existing climatic conditions.

Charpentier thought at first that the glaciation might have been due to the former greater height of the Alpine system; but he afterwards modified his opinion in so far as he regarded an exceptionally high rainfall in addition to a low temperature as a necessary condition in the accumulation of immense masses of ice. Charpentier argued that the atmosphere must have been loaded with moisture, which became condensed over the high Alpine regions.

Many attempts have been made to explain the Pleistocene climate, sometimes cosmic causes, sometimes telluric causes being selected as the more important. Sir Charles Lyell ascribed the climates of geological epochs solely to telluric influences (*ante*, p. 192). He thought the Ice Age in Europe and North America was explicable upon some such assumption as a close grouping of islands round the North Pole, a heightening of the continental territories between 70° and 80° latitude, a submergence of the temperate zone below the ocean, and a diversion of the warmth-giving Gulf Stream. Escher von der Linth and Desor brought forward (1863) in support of this theory their conclusion that the Sahara had been totally submerged during Pleistocene time, and that the consequent absence of the warm Föhn wind must have lowered the temperature of Central and Southern Europe. It has since been shown by Dove that the Föhn wind does not come from the Sahara, and Zittel and other scientific explorers of the Sahara have disproved the old idea that the Sahara was under water during the Pleistocene age.

The principle involved in Lyell's theory was accepted by Sartorius von Waltershausen and Stanislas Meunier, who assumed a much greater height and breadth of the mountain-systems as the chief modifying cause. Meunier showed that the accumulation of snow and ice on extensive mountain plateaux would of necessity lower the temperature. The Norwegian geologist, K. Pettersen, believed that an Arctic continent existed between Greenland and Spitzbergen during the Ice Age.

The explanations which have received the widest recognition are, however, based upon cosmic causes. The French mathematician, Adhémar, in 1832 contributed a remarkable paper on the "Revolution of the Sea: Periodic Deluges." He

drew attention to the eccentricity of the earth's orbit round the sun, and the fact that during the summer season of the southern hemisphere the earth is in its nearest position to the sun (perihelion), while during the winter season of the same hemisphere the earth is at its greatest distance from the sun (aphelion). He then argued, since the eccentricity of the orbit was variable, sometimes having the form of a long ellipse, sometimes approximating to a circle, during the epochs of greater eccentricity of the orbit, the hemisphere whose winter falls in aphelion would undergo a protracted period of winter cold. The climate might be thereby rendered so severe that stupendous masses of ice would accumulate near the Pole in aphelion, and as a further consequence the centre of gravity of the earth might be shifted. According to Adhémar, the conditions favourable for extensive glaciation recur in each hemisphere at intervals of 10,500 years, and thus call forth periodic Ice Ages.

Although Sir John Herschel, Arago, and Humboldt were of opinion that the eccentricity of the earth's orbit could have but a slight influence upon the climate of our planet, Adhémar's theory was accepted by Julien (1860) and Le Hon (1868) with scarcely any modification. James Croll treated the subject of cosmic causes of climatic variation in a memorable work, *Climate and Time* (1875). He improved the theory enunciated by Adhémar, inasmuch as he showed the dependence of the prevailing winds and ocean-currents upon the eccentricity of the earth's orbit, and explained how masses of ice and snow accumulating at the Pole must, in virtue of their radiation of cold, absorption of heat, and condensation of moisture, tend strongly to reduce the temperature. Croll supposed that the interglacial periods were characterised by the almost complete withdrawal of the glacier ice, and by extensive subaerial disturbance of the glacial deposits. In Great Britain, Croll's views have been accepted by many geologists, amongst others by Sir Archibald Geikie and his brother, Professor Geikie. Professor Penck and Professor Pilar are the best known of Croll's adherents on the Continent.

Sir Charles Lyell took objection to Croll's theory, mainly because of the insufficient geological evidence of recurring epochs of glaciation; nor can this objection be said to be even yet overcome. Neumayr doubts, on the one hand, whether

variations of eccentricity could affect climate to such an extent, and on the other, he thinks Croll's whole chain of argument valueless, since, excellent as it is, astronomy has not yet ascertained with any security that there have been periods of very great eccentricity of the orbit. Poisson (1837) suggested that climatic variations might result from movement of the solar system through warmer and colder portions of space; other authors have suggested changes in the obliquity of the ecliptic or a shifting of the earth's axis as possible causes of variation, but science has not yet arrived at any generally accepted solution of the difficult climatic problem of the Ice Age.

D. *Geological Action of Organisms.*—Scientific research has abundantly shown how subtle is the chemistry of life, and how important and complex is the part played by the organic world in the economy of nature.

Plants and animals abstract from the atmosphere, from the soil and the rocks, certain inorganic constituents which enter into new chemical combinations in the active tissues of the living organisms, and are partly assimilated, partly returned in altered form to the atmosphere and the ground.

Animal creation thus serves as an intermediary between the atmosphere and the earth's surface, utilising and metabolising matter derived from both, and effecting transferences from the one to the other.

The present action of living organisms upon the earth's surface is therefore partially to destroy, partially to renew and enrich it; and similar functions were fulfilled by living organisms in past ages. But more important for geology than the changes effected by metabolism and mineral decomposition is the consideration of the additions made to rock-deposits by the accumulation of organic remains.

The destructive effects of plant-growth are produced in virtue both of chemical and mechanical agencies. When plants decay, organic acids develop, and, as Bischof and more recently Julien have shown, these have a strong solvent and oxidising action upon the surrounding mineral matter. More especially when combined with water they promote rapid decomposition of the rocks, and their disintegrating action, productive of soil, may be traced to considerable depths below the surface. The roots of plants as they penetrate downward through the rock-fissures exert a certain mechanical force upon

the rocks. Even the rootlets of grass and other vegetation bore their way through sub-soil, and thus prepare an easier path for the infiltration of surface water and its combination with the organic acids as it proceeds on its subterranean passage. While, therefore, a thick covering of vegetation helps to protect the ground from sudden landslips and rapid surface denudation, and has a beneficent influence upon climate, the decay of vegetation slowly and surely rots any mineral matter within reach of the powerful humus acids.

Peat-mosses occupy wide areas in the Temperate and Arctic zones, and have been frequently made the subject of scientific researches. In 1810, Rennie published his work, *Essays on Peat-Moss*, an able treatise on the Scottish peat-mosses; and the nature and origin of peat-deposits were afterwards elucidated in handbooks by Dau (1823) and Wiegmann (1837). What Rennie achieved for the Scottish peat-mosses, was done for the Danish and North German peat-deposits by Steenstrup (1841) and Griesebach (1845). These authors defined for the first time the differences between Sphagnum mosses characteristic of marshes on mountain-slopes and valleys; low-lying or lacustrine growths and deposits of peat rich in rushes and sedges; and forest-peat or swamps. A typical example of a forest moss is the "Dismal Swamp" in Virginia, which Lyell described in 1841, and Lesquereux afterwards examined in more detail.

Modern deep-sea researches have discovered a few instances of marine peat; and according to the new investigations of Eugène Bertrand, isolated coal-beds occur which have been mainly formed by sea-weeds, for example the "Boghead" coal, near Autun, and the "Kerosene" in Australia. The low coasts, estuaries, and river-mouths in tropical lands are frequently fringed by mangrove-trees whose withered roots and fallen radicles form coaly deposits on the sea-floor, mixed with a large proportion of the finer coastal detritus. In a similar way, drift-wood may accumulate in large rivers, and by the process of subaqueous decay may be converted into lignite, or a substance of the nature of brown-coal. Lyell's description of the "rafts" of the Mississippi will be familiar to most readers.

Fossil brown-coal may be compared with these recent formations. The origin of brown-coal from plant-decay has never been questioned. A valuable monograph on brown-coal, describ-

ing its physical and chemical constitution, its palæontology, geological occurrence, and geographical distribution, was published by C. F. Zincken in 1865.

Fossil peat-deposits occur, so far as at present known, only in the post-Tertiary or Quaternary formation. The black-coal deposits of the old formations were frequently compared in geological literature with brown-coal, but the homogeneous structure and the rarity of good plant-remains in black coal, threw great doubt upon this explanation of its origin. Agricola, in 1544, explained it as condensed petroleum, and his opinion still found favour with Voigt in his special work on Coal-deposits (1802) and with Buckland (1822).

Kirwan, the opponent of Hutton, even explained coal as a product of the chemical decomposition of Archæan rock, while Andreas Wagner supposed it to represent condensed and deoxidised carbonic acid derived from an atmosphere supersaturated with carbon dioxide. Many of the geologists in the eighteenth century upheld the correct explanation; amongst others Scheuchzer in 1706, Beroldingen in his work on *Controversial Points in Mineralogy* (1778), and James Hutton in Great Britain (1785). But it was not until the microscope was applied to its investigation that the origin of coal from plant-growth *in situ* was securely established. In 1848, the German botanist, Dr. Heinrich Goeppert, proved that the vascular cryptogams and conifers whose remains accompany coal-formations had supplied the material of the deposit. His results were corroborated by Dawson in 1859; but even after this date erroneous conceptions from time to time were advanced with regard to the kinds of vegetation which had given origin to the coal-deposits. A decisive paper on the subject was contributed by Gümbel to the Bavarian Academy of Sciences in 1883, wherein he gave microscopic sections showing the fine textures of the various plant-remains in peat, brown coal, black coal, and anthracite.

The transformation of decayed plant-remains into coal takes place under the fundamental condition of limited access of air, and is promoted by heat and pressure. There is little doubt that all three factors have contributed to the origin of the deposits of black coal, and Bischof suggested that the characteristic chemical and physical constitution of the varieties of coal had been determined by definite relations in the amount of air admitted and in the accompanying heat and

pressure. A considerable loss of substance takes place during the transformation; Bischof reckoned that a mass of plant material about eighty feet thick will only yield a coal-seam about three feet in thickness.

There still continues a difference of opinion whether black coal originated *in situ* or if the plant material had been drifted and deposited in the same way as other sedimentary rock. Lyell, Logan, Goeppert, Gümbel are among the geologists who supported the view that the transformation of the vegetable matter took place *in situ*, as in the case of the large proportion of peat-mosses, and this is the common opinion of geologists.

In France, however, the theory of sedimentation is strongly supported. Grand-Eury, the author of an excellent work published in 1882, upon the flora of the Carboniferous formation of Central France, came to the conclusion that the coal-seams had originated by deposition in lake-depressions surrounded by woods. Five years later, the *Études* of Henry Fayol on the Coal-deposits of Commentry brought forward a strong chain of evidence in favour of sedimentation from water. Fayol shows how the pebbles, sand, mud, and plant detritus borne in suspension by rivers subside according to their weight, and arrange themselves as independent layers of sediment. The coarser pebbles are deposited near the shore, usually with a distinct slope, while the light plant detritus is carried far out and deposited almost horizontally.

In accordance with the amount of rainfall, the volume and velocity of the inflowing water vary, likewise the erosive action of rain and river water and the quality of the sediments. So that the alternation of conglomerate, sandstone, shale, and coal-seams observed in most coal-basins finds, according to Fayol, a natural explanation upon the basis of increase and decrease of rainfall without assuming oscillations of ground-level as has been done by the supporters of the coal-swamp theory of origin.

De Lapparent has not only accepted the views of Fayol and applied them generally to coal-basins, but also supported them by further arguments. It is in no small measure due to the prestige of this gifted geologist that the sedimentation theory is held by the majority of French geologists at the present day. A slight modification of the theory was recently advanced by Ochsenius (1892), who suggests that river-bars controlled the admission of the inflowing water into the lake-basins.

When the river-water was low, only the most buoyant plant detritus could be floated across the bar; when the water level was high, sand and pebbles were also carried into the basin of deposit (*ante*, p 220).

Lake-deposits of siliceous earth ("kieselguhr") were discovered by Ehrenberg in 1837 to be composed of the silicified valves or fragments of valves belonging to unicellular plants of microscopic size, the Diatomaceæ. These plants exist both in fresh and salt water, and their remains have gathered on the floor both of inland lakes and the ocean. Ehrenberg first demonstrated the presence of diatom remains in the ground of Berlin, in the peat-mosses of the Lüneburg heath, afterwards in samples of pelagic deposits, and in the "kieselguhr" and "tripoli powder" of Bilin in Bohemia, Richmond in Virginia, and other places. The explorations of the *Challenger* Expedition proved that extensive areas of the ocean-floor were covered by the skeletons and fragmentary *débris* of diatoms. In 1889, Weed found that the separation of silica from the hot springs and geysers of the Yellowstone Park was largely accomplished by diatoms.

More important is the assistance rendered by certain plants to the elaboration of limestone. It has long been known that the formation of calcareous tufa is promoted by the growth of moss, rushes, and certain algæ. On the other hand, it was discovered comparatively late in the history of research that marine limestones sometimes attaining great thicknesses owe their origin to algal organisms. Philippi was the first to recognise, in 1837, that the pelagic Nullipores previously regarded as polyps or Bryozoa belonged to the group of Calcareous Algæ. The name of Nullipores was changed to Lithothamnia and Melobesia, and Unger in 1858 demonstrated the important part such organisms had played in the construction of the Leitha limestone in the Vienna basin during the Miocene period. Two important works on the subject were contributed and laid before the Bavarian Academy of Sciences by Gümbel in 1871 and 1872. These works not only added to the microscopic knowledge of the skeletal structures of the Lithothamnian group, but also proved that other skeletal remains widely distributed in the Alpine limestones, and which had been referred by Schafhäutl to the Bryozoa under the name of Diplopores, agreed with the structure of the Dactylopores.

Charpentier had previously included Dactylopores amongst the Foraminifera, and the name of Foraminiferal limestone rapidly began to be applied to the Alpine deposits in question. Meunier-Chalmas, however, showed in 1877 that the so-called Dactylopores were not Foraminifera and did not belong to the animal kingdom at all, but were Calcareous Algæ. In view of Gümbel's results, these algal organisms, under the new name of *Gyroporella*, were raised to a place of the first importance in the history of Alpine rock-building, since their aggregated remains form a very great portion of the enormous thickness of limestone and dolomite which adorn the Eastern Alps.

In his work on Chemical Geology, Bischof had expressed his opinion that the thick deposits of marine limestone occurring in the geological formations had been formed by pelagic faunas which derived the calcareous substance from the calcium carbonate in sea-water. Volger in 1857 showed that the source of the lime was for the most part not the very small proportion of lime carbonate dissolved in sea-water, but the gypsum or lime sulphate. Recent researches support Volger's results, and enter in more detail into the chemical processes by which the animal tissues are enabled to assimilate the lime as a carbonate, and to throw off the sulphur in chemical combinations with waste products, more especially ammonia.

The "tests" or "casings" of pelagic Foraminifera are sometimes calcareous, sometimes arenaceous, and are sometimes imperforate (*e.g.* Miliolina, Orbitolites), sometimes provided with a number of small apertures or foramina (*e.g.* Nodosaria, Globigerina, Rotalia).

D'Orbigny in 1825 examined both recent and fossil specimens of Foraminifera, and misled by the elaborate appearance of the shells, he placed them in affinity with the Nautiloid group of Molluscs, but since then the microscopic study of Foraminifera and the extended means of comparison with related forms of lowly animal life have shown this group to belong to the Protozoa (*Subd. Reticularia*, Carp.); from geological, geographical, and zoological sides of research, abundant evidence has been given of the pre-eminence of testaceous material in pelagic deposits.

As early as 1839, Ehrenberg proved that chalk rocks were composed of fossil Foraminifera, and demonstrated a similar aggregation of minute calcareous shells belonging to recent

Foraminifera in certain fresh samples of ocean deposit. But it was not until 1871, by means of the *Challenger* Expedition, that any approximate estimate of the composition of typical pelagic oozes could be formed. The report by Murray and Renard (1891) on deep-sea deposits discloses the great importance of Globigerina ooze, which covers the floor, more especially of the central portions, of the Pacific Ocean, and is found at depths as great as 2,600 fathoms. It is more widely distributed than any of the other organic ocean muds, the Pteropod calcareous ooze, the siliceous ooze composed of diatomaceous material, or the Radiolarian siliceous ooze which is limited to very great depths of the ocean-floor. Littoral deposits are more mixed in character, usually comprising Molluscan, Bryozoan, and Echinoderman remains, although occasionally beds of individual types occur. Recent littoral deposits, on account of their more accessible position and the larger size of the faunas, have long been familiar to scientific observers, and were the first to be compared with fossil faunas in the rocks.

The activity of reef-building coral zoophytes has been one of the most interesting themes in modern scientific research. The red coral of the Mediterranean Sea was highly prized by the nations of antiquity for its beauty, and has always been an article of commercial importance. The first mention of the coral growths in the Red Sea was by the Portuguese writer, Don Juan de Castro; in 1616, Pyrard described the coral atolls of the Maldive Islands; and in 1742, Peter Forskäl by a series of investigations on coral reefs determined that the calcareous material for their construction was separated from sea-water by a small sedentary polyp. The closer study of the coral animal has shown it to be an ally of the Sea-Anemone or Actinian polyp, from which it is distinguished by its habit of growing as colonies, and of building up calcareous skeletal supports for the soft fleshy parts.

Geology has contributed a vast store of information about the skeletal structures of reef-building corals in past geological epochs, and at the present day few questions are of such common interest to the various branches of natural science as those concerning corals—the determination of the present geographical distribution of coral reefs, the climatic and physical conditions of growth, the chemical transformations undergone by the skeletal structures after withdrawal of the

polyp, the thicknesses and areal dimensions attained in virtue of the continued upward growth and seaward extension of the reef, and the proportion of coral formations in the limestone and dolomite rocks of the Alps and other regions.

Reinhold Forster, who accompanied Captain Cook on his voyage round the world in 1778, expressed the view that the formation of coral reefs was limited to the seas of warm climates, and wrote as follows regarding the mode of construction :—"The reef is built up by the lithophyte worms from the ocean-floor until it comes within a very small distance of the surface of the ocean. The waves wash against this newly-built wall all kinds of *débris*, mussel shells, fronds of sea-weed, fragments of coral, sand, and other material, so that the submarine coral wall gradually increases in height, and begins to be seen above the surface."

The circular form of atoll reefs is explained by Forster as the result of a continued effort on the part of coral polyps to erect a wall protecting them from dominating winds. James Cook added a number of observations on reef-growth, supplementary to those of Forster; and John Barrow in 1806 made the first attempt to determine the thickness of coral rock on an island. Flinders prepared in 1801 a map of the reefs off the Australian coast, and in 1814 published an important cartographical work, in which he agreed with Forster's views on reef-growth. Péron in 1816 enumerated 245 islands of reef-coral, and determined their geographical position between 34° north and south latitude.

Valuable observations were made on the conditions favourable for the growth of reef structures by Chamisso and Eschholz, who accompanied Kotzebue's voyage of exploration (1814-18) in the southern seas. Adalbert von Chamisso, during a prolonged sojourn on an atoll of the Radack group, took accurate measurements, upon the basis of which he afterwards sub-divided coral reefs into three classes, coastal reefs, inland groups, and atolls. Atolls were described as circular or ring islands, rising like table mountains from the ocean depths and only showing a narrow edge above the water. Chamisso distinguished very emphatically the higher side of a reef directed towards the prevailing wind from the lower protected side, which is frequently interrupted, and through which a channel leads into the central lagoon of the island.

He doubted whether the calcareous rock-material of the reef

represented coral structures in their actual original position, and inclined rather to regard it as a stratified accumulation of coral *débris*, embedding sometimes larger masses of coral colonial growths. Chamisso followed Forster in supposing that the coral reefs began to take shape on the ocean-floor at considerable depths, and their own continued growth brought them ultimately up to the surface. At the same time, from the distribution of coral islands, Chamisso thought it probable that corals settled upon submarine ridges. Eschholz associated the form of the coral islands with the pre-existing form of submarine mountains, whose summits they crown. He explained the origin of atolls on the assumption that when a reef has arrived at considerable dimensions the corals flourish best on the outer edge under the constant wash of the breakers and surf, and the reef tends therefore to increase more rapidly there; the lagoon, which is seldom over 30 fathoms deep, in the opinion of Eschholz, arises from the decrease and even cessation of coral growth in the middle of the reef, where the refuse of molluscan shells and coral fragments accumulates and militates against the proper nourishment of the corals.

Immediately following the results of the Kotzebue Expedition, those of the Freycinet Expedition in the years 1818-20 became known. Quoy and Gaimard published their observations on the mode of life of reef-corals in the *Annales des Sciences naturelles* in 1825. They never found living reef-corals in greater depths than 25-30 feet, and therefore concluded that these polyps could only exist in shallow and warm water, and preferentially in protected bays little affected by storms. Judging also from the small thickness of the raised coral limestones at Timor, Ile-de-France, New Guinea, and the Sandwich Isles, they argued that coral reefs could never be very thick. In confirmation of this result they mentioned how frequently coral reefs occur in a direction continuing that of the mountain-chains on land, while the massive reefs are limited to submarine platforms sloping gently from the shore.

Henrik Steffens in 1822 suggested that coral atolls formed on the summit of submarine volcanoes around the crater of eruption, which was afterwards occupied by the central lagoon of the reef. The same hypothesis was advanced independently by Quoy and Gaimard, and during the Duperry Expedition of 1828 was more closely investigated and accepted by

Lesson and Garnot. The English navigator, Captain Beechey, took a number of soundings round the edges of coral reefs, and also arrived at the conviction that they were based upon submarine mountains, whose summits were never covered by more than 400-500 feet of water.

The considerable size of many atolls made it seem somewhat improbable that they had been erected upon isolated volcanoes, and this theory was opposed by Ainsworth in 1831. He thought that, in addition to the coral polyps in shallow waters, there might be certain species whose habitat was at greater depths. In explanation of the higher edge on the windward side of an atoll, he called oceanic currents to his assistance, and thought they compelled the polyps to build vertically, whereas on the leeward side nothing prevented them from extending the reef in horizontal direction. Charles Lyell was favourably inclined to the theory of a volcanic basis, but also stated in the first edition of the *Principles* that the inequality in the height of the atoll edges might be due to local variation of level, more particularly to local subsidences after earthquakes.

The famous memoir by Ehrenberg, "On the Structure and Form of the Coral Growths in the Red Sea," published in 1834 in the *Abhandlungen* of the Berlin Academy, represented the result of eighteen months' study in the particular localities. The treatise begins with an exhaustive historical account of the previous literature on reef-building corals and reef-forms. Ehrenberg then describes the form of the reefs in the Red Sea as ribbon-like submarine banks extending parallel with the coast-line, based upon gentle beach-slopes, and having their water surfaces about ½-2 fathoms below the water-level at high tide. There are no exposed reef-surfaces in the Red Sea, and the outer side of the reef has a steep cliff edge descending rapidly into greater depths. The rock underlying the reefs is either a porous limestone or volcanic material; the coral limestone itself forms only a thin surface layer about 1½ fathoms thick upon the basal rock. Hence Ehrenberg regards the corals not as the builders of new islands, but only as the preservers of islands already existing.

The German zoölogist agrees with Quoy and Gaimard on one of the leading points of controversy, namely, the small thickness of coral structures, and confirms their conclusion that the polyps can only exist in warm water not more than six

fathoms in depth. He accepts also the theory of a volcanic basis as the best explanation of atolls. The accuracy and completeness of Ehrenberg's researches in the Red Sea have been since confirmed by some of the best German authorities on coral life—Haeckel, Klunzinger, Walther.

The reefs of the Bermuda Islands were described by Nelson in 1837, and this author demonstrates reef-growth upon a rock-basis neither volcanic nor even firm and compact; in his conclusions regarding the origin of atolls he supports Ainsworth's views.

One of the most attractive books of the nineteenth century was undoubtedly Charles Darwin's great work, *The Structure and Distribution of Coral Reefs*, published in 1842. Ehrenberg's work had paved the way for broader conceptions about coral reefs; in it the barrier reef, which had in the older literature been kept in the background by the more aggressive features of the atoll, for the first time received its meed of attention. The balance of scientific knowledge regarding the barrier and the atoll was now fairly equal, and Charles Lyell's indication of possible modifications that might ensue in the reef-form under the influence of differential crust-movements also lay open in the recent literature when Darwin's master-mind came to the formidable task of considering all the known data and constructing a scientific generalisation.

Charles Darwin, while a member of the *Beagle* Expedition between 1832 and 1834, examined a large number of coral reefs, atolls, and volcanic islands in the Pacific Ocean, and described them with remarkable method and clearness. He classified coral structures in three groups, now universally accepted—atolls or lagoon reefs, barrier reefs, and fringing reefs. This special work contains a map of the geographical distribution of the coral reefs, and enriches our knowledge by a wealth of new observations on the mode of life of the corals, as well as on the relative part taken by the various coral types in the construction of the reefs.

Darwin confirmed the fact that reef-corals only live at small depths and in tropical areas, and proposed upon the basis of crust subsidence an ingenious theory of reef-growth which connected the three chief varieties of reefs by intermediate stages. Darwin's theory assumes that every atoll reef was originally the fringing reef of some island, but owing to the subsidence of the ocean-floor, the fringing reef was gradually

converted into a barrier reef, and finally, by continued subsidence of the floor, passed into the form of an atoll. The essential feature is a certain reciprocity between the secular movement of subsidence and the vertical or horizontal growth of the reef. Darwin brings the movements of the area of subsidence in the Pacific Ocean into correlation with the volcanic phenomena so widely extended in that ocean. Where fringing reefs still occur, he supposes that instead of subsidence, local elevation is taking place. The presence of barrier reefs and atolls, on the contrary, indicates a submergence of islands and a subsidence of the sea-floor.

The distinguished American geologist and zoologist, Dana, had abundant opportunity during the Wilkes Expedition (1839-41) of investigating coral reefs, and he accepted Darwin's theory on all the essential points. The apparent naturalness of Darwin's theory recommended it to all, and in 1860 it seemed to find striking confirmation from the geological side. In that year Ferdinand von Richthofen published his account of the geology of Predazzo, St. Cassian, and adjacent localities in the South Tyrol Dolomites. He described the limited local occurrence of dolomite or dolomite limestone cliffs, in many places 2000-3000 feet thick, and the varying age of the sedimentary deposits at the base of the cliffs. These were sometimes the tufaceous Wengen strata, sometimes richly fossiliferous Cassian marls, sometimes the older dolomite rocks (*Mendola Dolomite*), sometimes volcanic lavas. Von Richthofen suggested that the variation in the age of the deposits at the base of the calcareous or dolomite cliffs, as well as the great inequality in the dimensions of the cliffs, might be explained in the sense of Darwin's theory on the supposition that the cliffs represented coral reefs whose growth had increased during a prolonged epoch of subsidence of the sea-floor, and had spread over deposits of different ages at the base. Mojsisovics, in conjunction with other members of the Austrian Survey, afterwards examined the area in greater detail, and in 1879 published his work, *The Dolomite Reefs of South Tyrol*, in which he confirmed Richthofen's suggestion that the cliffs were fossil coral reefs, but declared the growth of the reefs to have been contemporaneous with the sedimentation of the earthy and volcanic rocks in the neighbourhood.

Gümbel, however, proved the frequent occurrence of species of gyroporella, or sea-algæ, in the dolomite rocks of South Tyrol,

and for this and other reasons he regarded them as in the main algal accumulations. Lepsius also thought there were no sufficient stratigraphical grounds for regarding the dolomite rocks of South Tyrol as other than a marine deposit. But the coral-reef theory of origin had very numerous adherents, and became a popular explanation for isolated limestone occurrences; for example, Oswald Heer wrote of fossil atolls and barrier reefs in the Swiss Jura mountains, and Dupont described fossil atolls in Belgium preserved in Devonian rocks.

Recent researches in the Dolomites represent the occurrence of coral reefs only in insignificant thicknesses seldom exceeding 150 feet, sometimes intercalated in the marly volcanic rocks, and sometimes in the calcareo-dolomitic rocks.

Several zoologists contested Darwin's theory—Wilkes in 1849, Ross in 1855, the German geologist Semper in 1863, upon the evidence of his exploration of the Pelew or Palaos Islands. He found there all the varieties of reef-growth in immediate proximity to one another, and older coral rocks were present upon the dry land. Hence an explanation based upon subsidence seemed inapplicable. Semper formed the opinion that the tidal conditions, the breakers, and ocean-currents were the chief influences which determined the particular mode of growth of a coral reef.

Similarly, Louis Agassiz (1851) and a number of American geologists had studied the coral formations of Florida and Tortuga, and could find no evidence of subsidence of the sea bottom on which the reefs were growing. These reefs have now undergone thorough investigation by Professor Alexander Agassiz, the son of the famous glacialist and geologist, and the conclusion arrived at by him is that the reefs are growing upon a submarine plateau formed by the accumulation of mud, sand, and organic remains. The prevailing winds and marine currents constantly bring new material towards the plateau, and as the latter continues to increase the corals are enabled to keep within reach of fresh food-supplies. The whole thickness of the Florida reefs, including both the coral limestone and the submarine shelf of deposit, was determined by borings to be about 50 feet. Agassiz is of opinion that the reefs of Cuba, Bermuda, and Bahama, and also the Great Barrier Reef of North Australia, may be explained in the same way as the Florida reefs.

Rein published in 1870 the result of observations made on

the Bermuda reefs. He found only evidences of elevation, and came to the conclusion that coral reefs could be formed wherever the fundamental conditions for the existence of the polyps were satisfied, and a firm basis of support was present; and it was quite indifferent whether the basis was a submerged coast, a submarine plateau of elevation, or a submarine volcano. Sir John Murray arrived at similar conclusions (*Proc. Roy. Soc. Edin.*, 1880). He does not accept the hypothesis that the atolls and barrier reefs of the Pacific Ocean are built upon a submerged continent, but believes the coral polyps settle upon isolated volcanoes which still are partly above the water, but have been in some parts abraded to the limit of the mechanical activity of the waves; and he correlates the different forms of the reefs with conditions of nourishment and processes of erosion and corrosion. Murray's explanation of lagoon reefs is that on the windward side the existence of the coral colonies is more prosperous, and the reef grows more quickly than on the leeward side, whose position is less advantageous for the constant renewal of food supplies. The polyps on that side die, and the reef passes through processes of decay; the excavation of the saucer-shaped lagoon is due to the corrosion of the reef limestone by sea-water strongly impregnated with carbonic acid, and also to the erosive activity of the high tides.

Another important point in which Murray differs from the results attained by Darwin and Dana is the thickness of coral reefs. He shows from numerous soundings taken along the outer edge of atolls and barriers, that the reef-wall is precipitous only to a depth of about 200 feet; below that there is a talus slope occupied by broken blocks of coral limestone to depths of about 1000 feet; and fragments of volcanic material begin to occur at still greater depths.

In the Salomon Isles Guppy found older coral reefs that had been elevated to heights of more than 900 feet, but the reefs were not more than 130 feet thick.

In general, it may be said that most scientific authorities on coral reefs at the present day no longer accept Darwin's theory of widespread subsidence as applicable to the American and Australian reefs, or to those of the Red Sea. On the other hand, subsidence seems to be the most satisfactory explanation of many atolls in the Pacific Ocean. Clearly the critical test for subsidence is the thickness of a reef. The borings undertaken at the Ellice Isles, under the guidance of Professor Sollas

in 1896, had unfortunately to be given up on account of disasters to the instruments. The expedition sent out from Sydney University to the Funafuti Atoll under Professor Davis in 1897 was more successful, and the preliminary reports state that the borer passed through 643 feet of reef limestone without reaching the fundamental rock. But until the bore samples have been examined microscopically no opinion can be formed regarding the true nature of the limestone. Professor Agassiz visited the Fiji group in 1897, and observed massive coral reefs more than 600 feet thick in several of the islands. As these reefs had been elevated, Agassiz points out that the Pacific Ocean in the vicinity of the Fiji Isles cannot be at present undergoing the movement of subsidence assumed by Darwin and Dana, but rather a movement of elevation, although these massive coral reefs must have been formed during some foregoing period of subsidence.

Some of the most remarkable products of organic activity are the hydrocarbon compounds which, in the form of asphalt, naphtha, petroleum, impregnate sedimentary rocks belonging to different geological ages. Fluid petroleum is usually accompanied by greater or less quantities of inflammable gases, while these may be absent in the rocks impregnated with asphalt or other solid bitumen. Petroleum and naphtha occur exclusively in deposits from salt-water, and very commonly in loose sandy strata or in porous dolomitic and calcareous rocks where these repose upon, and are succeeded by, impervious shales.

In Pennsylvania, Ohio, and Indiana, certain horizons of the Silurian and Devonian formations contain enormous quantities of petroleum and inflammable gases; the naphtha and petroleum wells at Baku on the Caspian Sea, and at Grosny on the north side of the Caucasus, are apparently inexhaustible; and in Further India the so-called Rangoon oil has been found in quantity. The Caspian, Caucasian, Roumanian and Galician petroleum occurs in sandy strata of Oligocene age; both here and in Pennsylvania the oil is always in greatest abundance at the crests of crust anticlines.

During the last forty years geologists have rapidly advanced our knowledge of the occurrences of these natural oils, but it has been less easy to explain the process of their manufacture in nature over extensive areas. Berthelot, the chemist, suggested (1866) that they were produced when water with

carbonic acid in solution came in contact with the alkali metals. Mendelejeff likewise believes in the action of subterranean water upon certain iron ores and metallic carbides at high temperatures. But these theories have not been accepted by geologists, as they are not in harmony with the occurrences of the oil. All other hypotheses consider the decay of organic substance essential to the production of the series of mineral oils. Bischof in his Chemical Geology derives asphalt and petroleum from the slow decay of vegetable matter, an explanation which he bases upon the frequent occurrence of marsh-gas in peat-mosses. Quenstedt thinks the impregnating oil in the Swabian shales has been originated by the decomposition of fishes and other animal organisms interred in the shales. A similar explanation is given by Sterry Hunt for the petroleum oils in North America. While Quenstedt and Hunt regard the oil as produced *in situ* in the strata containing the decaying organisms, many geologists hold the opinion that the hydro-carbonaceous products of decay collect in the stratigraphical horizons above those which actually contain the decaying material.

Engler tried experimentally to distil fish-train oils; under a pressure of 20 to 25 atmospheres, and at a temperature of 365° to 420°, a distillate is procured which approaches the characters of the natural Pennsylvanian petroleum, and, as Heusler has shown, after treatment with aluminium chloride, is identical with it.

Ochsenius argues that the mineral oils have been prepared pre-eminently in shallow estuaries where animal remains and algæ have undergone decomposition in salt-water containing a rich supply of chlorides, more particularly magnesium chloride.

It has been observed by Andrussow, Natterer, and Barrois, that petroleum in minute quantity bubbles up to the surface of the water and mud in the Kara Boghaz on the shores of the Caspian Sea, in Bitter Lakes of the Isthmus of Suez, and in the desiccating saline basins of Brittany, all of these being localities where considerable accumulations of animal remains and plant detritus collect.

E. *Volcanoes.*—The controversy between Neptunists and Volcanists, which had still continued keenly in Germany during the early years of the nineteenth century, relaxed after the desertion of Alexander von Humboldt and Leopold

von Buch from the ranks of extreme Wernerians. Nowhere was the re-action in favour of accurate investigation of volcanoes keener than in Germany, where Werner's remarkable influence had so long retarded progress in this important branch of teaching. Von Humboldt's works (p. 66) gave the first broad conceptions of the arrangement and distribution of volcanoes on the earth's surface. From the characteristic arrangement of volcanoes either as groups or in long series, from their occurrence in all parts of the globe, and from their frequent association with earthquakes, Humboldt concluded that the cause of volcanic phenomena could not be local, but must bear some relation to the constitution of the earth's interior. The serial arrangement of volcanoes led him to believe that the volcanic vents were disposed upon crust-fractures which extended to very great depths.

Leopold von Buch's visit to Auvergne in 1802 convinced this geologist that the volcanic phenomena of that neighbourhood could only have been produced by some general cause associated with the earth's internal heat. It was on this occasion also that Leopold von Buch formed his first crude conception of the theory which, under the name of "Elevation-Crater" theory, was destined to become notorious in geological controversy of the nineteenth century. At this time, however, Buch merely mentioned a central elevation of the Mont d'Or range caused by subterranean forces.

Von Buch's treatise, *On the Geognostic Relations of the Trap Porphyry* (1813), contains a careful account of the occurrence and mineral constitution of rocks belonging to the trachyte series. The central elevation, which he had assumed for the Mont d'Or and Cantal area, is in this work applied to other volcanic regions, for example to the Santorin Island, to the trachyte mountains of Hungary, and to the South American Cordilleras, and a distinction is drawn between true volcanoes and mountain-systems representing dome-like crust elevations pushed up by subterranean forces.

Accompanied by the Norwegian botanist, Christian Smith, in the summer and autumn of 1815, Von Buch explored the Canary Islands, the Palma Islands, and on the return voyage visited the Lancerote Island. The result of this journey was published independently by Buch, as Christian Smith died in the following year on the Congo river, where he had gone with Tuckey's Expedition. Von Buch's descriptive monograph of

the Canary Islands is full of information for the geographer, meteorologist, botanist, and geologist. The chapter on the geological relations is a model of skilful and methodical exposition. The form, the structure, the composition and origin of the different islands, the constitution of the rocks and volcanic ejecta, are depicted in a manner at once attractive and scientific, and the context is illustrated by topographical maps of Teneriffe, Palma, and Lancerote, prepared exclusively from surveys and drawings made by Von Buch. At the Peak of Teneriffe and in the wonderful basin-shaped depressions ("Calderen") in Palma and Canaria, Von Buch found new evidences of volcanic elevations. And from this time forward the "Elevation Crater" became one of his pet theories.

The first public enunciation of the theory was given by Von Buch on the 28th May, 1819, in the Berlin Academy. He defined true volcanoes as solitary, conical mountains almost always composed of trap-porphyry (trachyte), and from which fire, vapour, and stone are emitted. They are surrounded by molten rock or ashy material which flows downward in the form of streams. Typical volcanoes are distinguished by Von Buch's theory from larger basaltic masses which after emission have been uplifted around the areas of volcanicity. These volcanic uplifts were said to be characterised by the absence of lava streams or of accumulations of rapilli round a central area, and likewise by the predominance of basaltic over trachytic rocks. The basaltic masses are inclined similarly to sedimentary strata in any upheaved area ascending from every side towards a great central *cauldron, or crater of elevation.* This crater might be afterwards closed by the collapse of the upheaved rocks, and might be opened intermittently by fresh volcanic ebullitions from below.

Von Buch then argued that the force required to create such a crust-disturbance must be enormous, and must represent the prolonged accumulation of a store of energy in the earth's interior. The expansive force of the heated lava first bulging the rocks upward like a blister or dome, might go on increasing until it rent them asunder and provided an outlet for the ascending vapours. No true volcano formed unless, as frequently happened, a central cone of ejected material gathered within the crater of elevation.

The upper basaltic layers of the crater of elevation might,

LEOPOLD VON BUCH.

Von Buch allowed, have flowed into their present position, but not superficially like the lava streams of an active volcano, only below the surface and under great pressure. The more important points in Von Buch's chain of evidence were the occurrence of coarse-grained crystalline rocks in the bottom of the Palma cauldron, the general arrangement of the strata sloping away from the central crater and penetrated by numerous dykes, and the presence of deep ravines (Barrancos), which he regarded as eruptive fissures on the outer side of the crater of elevation. Von Buch thought craters of elevation were very numerously distributed; some of them originally embracing a central volcanic cone, for example, the island of Bourbon; others, such as those of Auvergne, the Siebengebirge near Bonn, the Lipari Isles, Etna and the American Cordilleras, being trachytic dome-shaped mountains situated above the fissures of elevation, and either remaining intact at their summit or providing themselves with orifices of ejection.

Von Buch sub-divided all the volcanoes on the earth's surface into two classes—*central* and *serial*. The former, according to Von Buch, are located centrally with reference to a large number of outbreaks radiating in all directions; the latter mark the position of long crust-fissures, and either form the highest ridge of a terrestrial mountain-system, or if the volcanic fissure be submarine, the highest summits emerge as islands above the ocean.

While Von Buch in his theory tacitly accepted Hutton's principle, that the upheaval of the solid rocks was due to the expansive force of subterranean heat, he re-cast this doctrine into the particular form required to explain his own conceptions of volcanicity. He formed the erroneous idea that the inclination of the basalts around a volcanic vent could only be due directly or indirectly to crust-elevation, and this view shipwrecked a theory which otherwise embodied some valuable generalisations. Adapting his theory to the terminology of the present day, Von Buch's conception of a "*Central* elevation-crater" represented a *local* exhibition of crust-expansion accompanied by a *local* inrush of molten and gaseous material towards a centre of crust-weakness, and the escape of the same at a central vent; Von Buch's "*Serial* elevation-craters" represented the results of a *regional* exhibition of the expansive forces due to internal heat, and *regional* admission of molten rock and gaseous vapours into zones and areas

of weakness. His description of basaltic inflows into subterranean cavities formed by crust-expansion and elevation anticipated later conceptions of laccolitic occurrences of volcanic material.

Before Von Buch had completed his work on the Canary Islands for publication, the Englishman, Dr. Daubeny (1819), published a tabulated summary of active volcanoes, together with an enumeration of all volcanic and earthquake phenomena reported within historic times. In 1824 the second volume of Carl von Hoff's work appeared, and it embraced an exhaustive account of surface changes associated with volcanic outbreaks and earthquake shocks. Von Hoff followed the opinions of his compatriots, Humboldt and Buch, on all questions regarding the origin and destruction of volcanoes.

A series of careful researches was carried out in the volcanic areas of the Rhine Province by Johann Steininger, a teacher in the Treves public school. Steininger established the difference between the volcanic rocks of the Eifel district and the trap-porphyry rocks (melaphyre, porphyrite, palatinite) of the district of Oldenburg and the Palatinate. Both were regarded by Steininger as submarine in origin, but he referred the eruptions to quite different geological ages. He pointed out that a characteristic feature of the Eifel volcanoes was the frequent occurrence of lava and volcanic slag and ash without any sign of an orifice or eruption. The volcanoes of the Lower Rhine district, especially the Siebengebirge, near Bonn, were explained as upraised conical mountains in which the volcanic material seldom escaped at the surface. In his *Contributions to the History of the Rhineland Volcanoes*, published in 1821, Steininger proved that a certain number of the volcanoes, chiefly those on the right bank of the Rhine, had originated contemporaneously with the formation of the brown-coal deposits (Tertiary), and were therefore older than the pebble and clay deposits with fossil mammalian bones (mammoth, rhinoceros); but, he added, the products of the youngest volcanoes on the left bank of the Rhine seemed to be distributed above these pebble-beds, and might accordingly belong to historic times. The idea of the quite recent occurrence of those volcanoes originated from a mistaken reading of a reference made to the volcanoes of this area by Tacitus.

In his earlier writings Steininger was under the influence of Von Buch's theory of elevation-craters, but his close

acquaintance with the mode of occurrence of the volcanic rocks in Rhineland enabled him gradually to form his own judgments, and these were unfavourable to Von Buch's theory. A visit to Auvergne, Mont d'Or, and the Cantal mountains still further shook his confidence in it. He examined the basaltic rocks above the Tertiary fresh-water limestone of Limagne, and felt convinced that these could not have been bulged up as solid rock from the ocean-floor, but must have flowed into their present position superficially as a lava. Again, he could see no evidence in favour of Von Buch's hypothesis that the ravines of the Cantal represent eruptive fissures formed during upheaval, but rather believed them to be ordinary erosion valleys. Steininger, however, continued to retain Von Buch's theory of volcanic upheaval as applicable to the particular cases of isolated conical hills composed of domite or trachyte rock.

The strongest opponents of Von Buch's theory were, however, Poulett-Scrope,[1] Charles Lyell, and Constant Prévost.

In 1816-17, Poulett-Scrope, as a young student, had the opportunity of observing the volcanic surroundings of Naples, and this gave the impulse to his scientific studies. He returned in 1818, 1819, and 1822 to Southern Italy, and visited Vesuvius, Etna, the Lipari Isles, the neighbourhood of Rome, and the Euganian Isles. In 1821 he spent several months in the Auvergne district, and in 1823 he made himself acquainted with the Rhineland and Eifel volcanoes described by Steininger.

In 1825 he published his famous work on Volcanoes, and in 1826 his excellent monograph of the extinct volcanoes in Central France. Poulett-Scrope's works have held their position as the basis of volcanic teaching. Like Hutton and his own contemporary, Charles Lyell, he was a Uniformitarian, and tried to explain the events of past geological ages by the action of forces which exist.

Observing the enormous expansive force of the aqueous

[1] George Poulett-Scrope was born in 1797 in London, the son of a rich merchant, J. Poulett Thomson; he studied in Cambridge under Professor Sedgwick, and assumed the name of Scrope after his marriage with the heiress of the old Scrope family. He became a Member of Parliament in 1833, and afterwards devoted himself mainly to political activity, but did not neglect his studies on volcanoes. In 1867 the Geological Society conferred the Wollaston medal on him. He died at Fairlawn, Surrey, in January 1875.

vapour and gases which escaped from a lava stream at the surface, Scrope formed the opinion that eruptive phenomena might be traced to the mobility of the lava. According to his observations, lava, as it issues from a volcanic vent, very seldom has the appearance with which we are familiar in a hot mass of iron or glass, but is usually in a viscid, seething condition, impregnated with elastic vapours, and enclosing many crystallites which move freely in the surrounding fluid in virtue of the passage of the vapours through it. As the vapours explode and escape, the motion of the mineral constituents is impeded and the lava solidifies. Scrope applied this theory to subterranean lava. He supposes a fused rock-mass saturated with water, under pressure of superincumbent solid rock; then the pressure being the same and the temperature raised, or the temperature being the same and the pressure relaxed, the water will pass into the condition of vapour, and a certain amount of heat be made latent. The crystalline constituents of this subterranean magma are separated by the elastic vapour, the lava swells and passes into a fluid condition. The degree of liquidity in the whole mass was thought by Mr. Scrope to depend chiefly on the weight of the mineral constituents and the fineness of the crystals. If the subterranean lava be horizontally extended, the compressed vapours, in trying to escape, press the lava against the upper strata, cause earthquakes, and finally fissures into which the seething lava flows. If the fissures widen towards the interior of the earth, the rising lava forms dykes, and as these narrow towards the earth's surface, they strengthen the crust; but if, on the other hand, the fissures are wider in the upper horizons of the crust than in the lower, they remain partially open, and form relatively weak parts in the earth's crust, readily liable to renewed eruptions.

Scrope endeavoured to explain all the phenomena associated with volcanic eruptions upon the basis of the above theory. In favour of it, he noted the periodicity in eruptive activity; how after each eruption, when presumably the fissures have been blocked with rock-material, a period of rest ensues, but when the vapours have once more accumulated in the deep volcanic magma, the old vent again bursts open or a new orifice forms. In the case of land volcanoes, the ejected products of successive outbursts surround these orifices with the characteristic circular or elliptical form. The particular

form of the volcano is determined by several causes, for example, the inequality of the ground, violent winds during eruption, or any obstacles within the vent which may impede the ascent of the lava, or direct it into another course. Stratification is apparent in the structure of the cone of ejection; it is especially clear when there is an alternation of lava and volcanic ash. The inclination of the layers of volcanic rock is always from the edge of the crater to the base of the cone. The liquidity of the lava depends on its composition, texture, and temperature, and according to these and to the superficial relations, the solidified lava assumes the form of horizontal sheets, thick masses, or dome-shaped cones. During the cooling of the lava the escape of the vapours gives origin to the slaggy, vesicular structure of the lava; the liberation of the gases from the lava produces all kinds of minerals, and may take place either in association with escaping vapours as "fumaroles," or independently as gaseous emanations or "solfataras"; sometimes the gases collect from hot springs, or they vanish as exhalations. Pillar-shaped, rounded, cubical, rhomboidal, flaggy or shaly structure develops in consequence of the contraction of the lava during the processes of cooling.

As one and the same volcano may emit basaltic and trachytic lavas, Scrope thought it probable that all volcanic products come from the same subterranean magma, and that their specific difference is due to some condition connected with the access of heat and the subsequent chemical processes during their ascent. Poulett-Scrope opposed the conception of Humboldt and Buch, that trachyte and basalt rocks are of different ages. The larger volcanic mountains, he said, clearly owe their origin and form to repeated eruptions; the original cones of ejection are rent by later outbreaks, and the repeated outpourings and injections of lava still help to strengthen the mountain. In the summit crater, for the most part only vapours escape, together with the blocks and fragments which are carried up by the explosions. Very wide and deep craters form during the violent paroxysms of a volcano; by means of the subsequent eruptions new cones of ejection may arise within this deep crater, and be surrounded by the circular wall of the old crater; or the wall of the old crater may be disturbed and partially destroyed by a new crater (Somma).

Scrope strongly contested the existence of craters of elevation,

and he ascribed the domal form of the trachyte mountains not to the swelling up of homogeneous masses, but to successive outbreaks of viscid lava streams. Neither did he draw any fundamental distinction between volcanic eruptions on land and those on the ocean-floor. Cones of erupted material form in the case of submarine as well as continental volcanoes, but owing to the distribution of the material by water, the layers of volcanic rock are less highly inclined and generally of tufaceous character. Some submarine volcanoes have their cones of ejection built up by repeated additions until they rise above the surface; others (*e.g.*, Île de France, Teneriffe, Palma, the Coral Islands in the Pacific Ocean) may, in Scrope's opinion, have been arched to their present position by the subterranean forces of heat. The difference between the "craters of elevation" of Von Buch and the uplifted islands of Scrope is that the former are supposed to have received their characteristic form and their crater, independently of any accompanying phenomena of eruption, merely by the upward swelling and fracture of the crust, whereas Scrope thinks the elevated submarine islands of volcanic rock are in all cases originally cones of erupted rock-material accumulated superficially round an orifice, and afterwards upraised as a whole.

Von Buch's "Serial Volcanoes" are explained similarly by Scrope as volcanic cones which participated in a crust-uplift. All volcanoes, according to him, occur upon crust-fissures; some eruptive vents are permanently closed, and others continue to remain in communication with the earth's interior, and are the scene of periodic eruptions. These open vents, by affording a ready passage for subterranean lava, vapours, and gases, serve to protect the neighbourhood from earthquakes. Scrope attached little tectonic importance to the elevations at volcanic fissures, regarding them as quite local in effect, and having no immediate connection with the regional crust-movements which elevate continents and mountain-systems.

The above are the leading doctrines of volcanicity taught by Scrope, and they may be said to have laid the first secure foundation of present conceptions of eruptive phenomena. The chief merit of Scrope's work consists in the convincing demonstration it gives of the origin and composition of volcanoes, in the disproof of the Elevation-Crater theory, and in the description of a superheated subterranean magma saturated

with water-substance, and brought to the surface in virtue of the expansive force of escaping vapours and gases.

Sir Charles Lyell held views very similar to those of Poulett-Scrope. His observations in the Auvergne, and at Vesuvius and Etna, had convinced him of the mistaken principles in the Elevation-Crater theory. He made the pertinent objection that one of the "craters of elevation" mentioned by Von Buch was entirely composed of marine or littoral sediments; and he explained the enormous "cauldrons" of Palma, Gran Canaria, Bourbon, etc., as craters due to volcanic explosion; and the circular walls of the Somma, the Peak of Teneriffe, Etna, etc., as the remainder of old crater walls. In common with Poulett-Scrope, Lyell ascribed the conical form of most volcanoes to the accumulation of volcanic products round a vent, and he accepted Scrope's view that volcanic eruptions were originated by the explosive disengagement of the compressed vapours and gases from subterranean magma. His wider geological experience, however, led him to the further conclusion that the water-substance dissolved in the magma had been introduced into it by percolation downward from the surface, and that the characteristic occurrence of serial volcanoes on the sea-board betokened direct influence of the sea-water upon the subterranean magma.

Dr. Charles Daubeny's *Description of Active and Extinct Volcanoes, etc.* (1826), although less full of original matter than the works of Scrope and Lyell on kindred subjects, was distinguished by greater chemical and mineralogical knowledge. His treatment of European volcanoes is based for the most part on his own field investigations of the various localities, and careful laboratory research of the volcanic rocks. Daubeny was favourably inclined to Buch's "Elevation-Crater" theory, and thought that Scrope attached too great importance to the expansion of vapours, and too little importance to chemical processes in his explanation of volcanic eruption.

Valuable results of a special study of the Lipari Islands were made known in 1832-33 by Friedrich Hoffmann, but the complete researches of this gifted writer were first published by Von Dechen after Hoffmann's death, in Karsten's *Archiv für Mineralogie*, 1839. Hoffmann contended that there was no essential difference in point of structure between the craters attributed by Von Buch to crust-elevation and fissure, and the

craters regarded by him simply as eruptive orifices. The alleged differences resolved themselves into a question of comparative dimensions, and these could be explained by the varying intensity of the explosive convulsions.

The French Government had sent Constant Prévost, in August 1831, to Pantellaria, in order to study the newly-formed Graham's Island, or Île Julia, as the French Expedition called it. The island vanished in three months, and Prévost was one of the few favoured individuals who had succeeded in visiting and making drawings of it. After fulfilling this commission, he travelled through Sicily, climbed Etna, made a stay in the Lipari Islands, and finally met Hoffmann and Escher von der Linth in Naples. Excursions made in the company of these geologists to Vesuvius and the Phlegræan fields brought Prévost's memorable tour to a conclusion. Several accounts of his journeys were sent by Prévost to the Academy of Sciences and the Geological Society of Paris.

Meantime, in Paris, Élie de Beaumont (1829-30) had discussed the Elevation-Crater theory in various publications, and had given it strong support; and when Prévost in his first report on the Island of Julia to the Academy ventured to doubt the theory, and in September 1832, in a second report, went so far as to openly deny the existence of elevation-craters in any volcanic district visited by him, he aroused the displeasure of all the leading members of the Academy. Only the venerable Cordier, who had seen the Canary Isles, expressed agreement with him. In the December of that year Prévost won a valuable ally in Virlet, who proved that the Santorin group, which had hitherto been included amongst elevation-craters, consisted wholly of ejected material.

In the following years controversy became as keen in the discussion of Buch's theory as it had been in Werner's time over the discussion of the volcanic or aqueous origin of basalt. Annoyed by the attacks on his favourite theory, Buch undertook, in the autumn of 1834, another journey to Italy along with Link, Élie de Beaumont, and Dufrenoy. New evidences were collected, and his views were afterwards pronounced even more firmly. "Craters of Elevation are," he wrote, "remnants of a powerful manifestation of energy from the earth's interior, which is capable of uplifting large islands many square miles in breadth to a considerable elevation.

No phenomena of eruption proceed from them; no volcanic event connects them with the earth's interior; and only seldom is there any evidence of continued volcanic activity within such craters, or in their neighbourhood."

The chief argument insisted upon by Buch was the high inclination of the lava flows, which he thought proved that they had been uplifted after their emission. He never accepted Scrope's explanation that the streams of red-hot magma could solidify in this position. Elie de Beaumont examined Etna, and, after accurate measurements of the angle of inclination, likewise refuted the possibility of solidification *in situ*. He allowed rather more significance than Von Buch to the accumulation of ejected scoriæ and *débris*, but held upheaval for the most important factor in the formation of a volcanic cone. Wilhelm Abich and Sainte-Claire Deville were amongst the more able supporters of the Elevation-Crater theory; Abich in his illustrative work on Vesuvius and Etna (1836), and Deville in his description of the Eruption of Vesuvius in 1855.

Von Buch's theory was now thought to have been successfully defended, and was accepted in the standard text-books, in the monographs of Daubeny and Landgrebe, and above all in the *Cosmos* of Humboldt. But the three chief antagonists of the theory, Constant Prévost, Lyell, and Poulett-Scrope, continued to publish their own views, and in two masterly polemical papers in the *Quarterly Journal of the Geological Society of London* (1856 and 1859), Scrope was able to endorse the opinions he had formed thirty years earlier, and to demonstrate the origin of volcanic cones from ejected material in a manner absolutely convincing.

During the following decade, corroborative evidence in the same direction rapidly gathered in geological literature. Dr. George Hartung, who had been with Sir Charles Lyell in the Canary Islands, and had also made a number of observations in Madeira and the Azores Islands, openly disputed Von Buch's views in Germany, and said that the present shape of the large "cauldrons" in Palma and Gran Canaria had been produced by erosion. Dana's investigations in the Sandwich Isles and Junghuhn's excellent descriptions of the volcanoes in Java added further records of volcanic cones built up by ejected material; and Fouqué in 1866 arrived at the conclusion that in the case of the Santorin Islands Buch's theory could not be applied. Thus the

hypothesis of Elevation-Craters had to be given up, and with it the classification of volcanoes into "True" or "Eruptive Volcanoes" and "Craters of Elevation" which had been so long associated with the names of Buch and Humboldt.

Karl von Seebach then proposed a new classification; he distinguished as *Stratified Volcanoes* those which have a crater and are composed of layers of lava and loose volcanic ash and scoriæ; as *Homogeneous Volcanoes* those which have no crater and no loose ejected material but have originated as massive effusions and have the form either of volcanic domes or horizontal sheets. The homogeneous volcanoes have been formed by viscous lavas, the stratified volcanoes by more liquid lavas strongly impregnated with vapour and gases. This sub-division into stratified and homogeneous volcanoes was adopted in most of the text-books, and was afterwards more firmly established by Sir Archibald Geikie and Dr. Reyer.

It is beyond the scope of this volume to enter into the extensive descriptive literature which is occupied chiefly with the configuration, composition, geographical distribution, eruptive phenomena, and history of the volcanoes. Humboldt published an epitome of all known volcanoes, and the works of Hoff, Daubeny, Scrope, and others supplemented the earlier lists.

Vesuvius is the best known volcano in the world, and during the prolonged controversy about elevation-craters was made more than ever the subject of close attention. Monticelli for thirty years, from 1815 to 1845, took observations on Vesuvius and its discharges; from 1855 to 1892 Palmieri published regular reports of the observations made in the Observatory of this mountain. Angelo Scacchi and Gerhard vom Rath examined the minerals of Vesuvius; the lavas were described by Justus Roth, the author of a monograph of Mount Vesuvius (1857), and by C. W. C. Fuchs. The last-named author also mapped and described the Island of Ischia (1872). Within recent years Vesuvius has been constantly under observation by Johnston Lavis and Matteucci.

The name of Baron Sartorius von Waltershausen is indelibly associated with Etna. His geological map (scale, 1 : 50,000) of this volcano appeared in 1861, and his descriptive text was published posthumously in 1880 by Lasaulx. The scrupulous accuracy and exhaustive details of both map and text amply entitle them to their rank as the fundamental work on Etna.

Von Waltershausen brings forward evidence to show that the first volcanic outbreak on Etna took place during the Diluvial period, while that area formed part of the Continent; whereas Pilla, writing in 1845, referred the first Etna eruption to the Pliocene age, or possibly to a still more remote period. According to Von Waltershausen, the volcanic eruptions are concentrated along a fissure extending in N.N.W.–S.S.E. direction; and the famous Val del Bove is thought by him to have originated as a crust-inthrow, and is compared with the crust-basins of Somma and Santorin.

The Lipari Islands have called forth a rich literature. Special interest has been accorded to a ringed series of islands and reef-rocks surrounding Stromboli on the south. Hoffmann in 1832 suggested that these probably represented the fragments of a former enormous crater. Professor Judd in 1875 confirmed this view, and also agreed with Hoffmann's conclusion that the vents of the volcanic discharges in the Lipari Isles virtually occur along the course of three radial fissures. Professor Suess expressed a similar opinion that the Æolian Isles mark a saucer-shaped depression in which radial faults intersect.

The Santorin Isles form the subject of a splendidly illustrated monograph by Fouqué. Since its publication in 1878, a number of geologists have contributed special papers on the surface conformation, the geological structure, the origin and history of these volcanic islands. All newer publications agree that the theory of the Elevation-Craters is quite inapplicable to Santorin.

The volcanoes of Iceland have been carefully investigated during the past century. Mackenzie's Travels gave the earliest detailed reports (1811); in 1846, the great chemist Robert von Bunsen travelled through Iceland, and published five years later his famous treatise on the chemical composition and origin of the volcanic rocks of Iceland. Within recent years the island has been accurately mapped by members of the Norwegian Survey Department, and important contributions have been made to the knowledge of its volcanoes by Thoroddsen and Keilhack.

The extinct volcanoes of Europe have received a large share of attention from geologists. The Euganian Isles near Padua, and Monte Berici near Vicenza, have been studied by Dr. vom Rath, Dr. Reyer, and Professor Suess.

The extinct volcanoes of Central France, the Eifel and the Siebengebirge, have been frequently mentioned in the foregoing pages. Other favourite themes in geological literature are the basalt and trachyte domes of the Westerwald, the extensive volcanic district of the Vogelsgebirge, the extinct volcanoes in the vicinity of Cassel, in the Habichts Forest, Kaufung Forest, and the Meissner Mountain. As early as 1790, a mineralogical study of the Meissner was published by J. Schaub, and a geological map of this mountain appeared in 1817.

The Rhön has a historical interest for geology, as it was the basis of Voigt's attack on the Neptunistic doctrines of his teacher Werner. The mode of occurrence of the phonolite and basalt bosses in the Rhön convinced Voigt of their volcanic origin. The first complete description of the Rhön was given in 1866 by C. W. von Gümbel, in whose works on Bavarian geology will be found all the important features of the ancient centres of volcanicity in the Bavarian Forest. Another district exhaustively treated by Gümbel is the volcanic inthrow of the Ries. The basalt hills and tuff dykes of the Swabian Alp have been examined by Quenstedt (1869), Zirkel (1870), and more recently by W. Branco (1894). Professor Branco contests the hypothesis that all volcanoes occur upon tectonic fissures and faults.

In the Höhgau in Baden phonolite and basalt mountains rise to a height of nearly 3000 feet. They present for the most part the characteristics of homogeneous volcanic rock, but are partly accompanied also by masses of tuffs. The pretty little volcanic mountain known as the Kaiserstuhl rises from the Rhine Plain between the Black Forest and the Vosges mountains. Baron von Dietrich in 1774 was the first to recognise its volcanic origin.

The basaltic bosses in Thuringia, Saxony, and Silesia, as well as the extinct volcanoes in North Bohemia, Hungary, and Transylvania, have been the subject of petrographical papers, but have had no marked influence upon general conceptions of volcanism. The Kammerbühl near Eger has some historical interest, and a new paper was published upon it by Prost (*Jahrbuch*, 1894).

The writings on the district of Predazzo and the neighbouring parts of the Fassa Valley and Schlern fill an important page in the history of volcanism. In 1819 Count Marzari

Pencati had drawn attention to the fact that not far from Predazzo, at the waterfall of Canzacoli, true granite covered the Alpine limestone and had altered it to marble. Leopold von Buch doubted in 1821 the position of the granite above the limestone, but allowed that the granite had produced the metamorphism of the limestone to marble. Then followed Buch's famous papers on dolomite, and on the geology of the Fassa Valley, in which he on the one hand tried to explain the origin of the dolomite by the action of magnesia vapours during the eruption of augite porphyry, and on the other hand associated the upheaval of the Alps with the outbreaks of augite porphyry.

Buch's declaration that in South Tyrol lay the key to the solution of Alpine geology, attracted geologists from all countries to this neighbourhood. The "Triassic granite" and Monzoni syenite, with their wonderful array of contact minerals, the dykes and massive sheets of augite porphyry, melaphyre and liebenerite porphyry, were described by several geologists. In 1824 Poulett-Scrope, Studer, and Ami Boué visited Predazzo; in 1843 Von Klipstein published his observations on the Fleims and Fassa Valley; in 1855 the Norwegian mineralogist, Kjerulf, published his accurate mineralogical and chemical investigation of the Monzoni syenite.

Baron von Richthofen's monograph, published in 1860, still forms the best foundation for the geology of South Tyrol. He determined a definite succession in the Triassic eruptive rocks—first the basic series, augite, porphyrite, monzonite, and hypersthenite, then flows of lava, or the infilling of fissures by tourmaline granite, melaphyre, and liebenerite porphyry. Three years later Bernhardt von Cotta's paper appeared on the intrusions and ramifications of the Monzoni syenite into the limestone, on contact minerals, and on the melaphyre dykes in the limestone and dolomite. Lapparent in 1864 sub-divided the eruptive rocks of the neighbourhood into a basic and an acid group, without entering into the particular succession, but Doelter's petrographical studies led him to much the same conclusion about the succession as Richthofen had formed. Reyer, on the other hand, thought that granite and then syenite had been intruded during the Muschelkalk period; monzonite, porphyrite, and andesite had followed; but in his opinion the same eruptive series had been repeated in various geological epochs. Mojsisovics' work, *The*

Dolomite Reefs of South Tyrol, supplies a comprehensive account of this district, and forms the text to the Austrian Geological Survey Maps.

More recently the Norwegian geologist, Professor Broegger, has drawn a comparison between the rocks of the South Tyrol eruptive area and those of the Christiania area. He demonstrates that Richthofen's "Melaphyre" of the Mulatto mountain is not younger but older than the tourmaline granite, and that altogether the basic eruptions of augite, porphyrite, plagioclase porphyrite, and melaphyres in the Fassa Valley for the most part preceded the intrusion of the granite. Only a few ultra-basic dykes which penetrate the granite at Predazzo are younger than it. Broegger arrives at the conclusion that granite, monzonite, hypersthenite are only the deep-seated equivalents of the Triassic outflows of porphyrites and melaphyres; and his comparison of the Predazzo and Christiania areas leads him to assign a Triassic age to the granite masses at Brixen, and to the tonalite, adamellite, and banatite of the Riesenferner group, the Adamello group, and Cima d'Asta.

The extinct volcanoes of the Western Isles of Scotland were first described by MacCulloch (*ante*, p. 113). Ami Boué, in his *Geological Essay on Scotland* (1820), distinguished very exactly between basaltic sheets and dykes, and described the various volcanic rocks petrographically. Although a student of Jameson, he attached himself to Hutton's party in regard to the origin of basalt, phonolite, trachyte, porphyry, and granite.

L. A. Necker, the grandson of the great Saussure, travelled in Scotland and the Western Hebrides in 1823, but his account of his journey contained little that was new. The observations of Von Oeynhausen and Von Dechen, published in Karsten's *Archiv* in 1826, were of some importance for the geology of Skye, Eigg, and Arran.

In 1850, the Duke of Argyle discovered in the Island of Mull sedimentary beds with flint nodules belonging to the Cretaceous series, and fossil remains of dicotyledonous plants between basaltic flows. The fossils were determined by Edward Forbes to be of Tertiary age; nevertheless the same author referred the basalts of Skye to the Jurassic epoch. In 1861, Sir Archibald Geikie began that brilliant series of researches which extended over a period of thirty-five years, and made the Western Isles of Scotland a classical area for the study of extinct volcanoes.

Geikie at first agreed with Edward Forbes as to the geological age of the basaltic flows in Skye, but further researches led him to form another conclusion, and in 1867 he wrote that all the eruptions of basalt in the Western and the Faröe Isles, as well as those in Iceland, had taken place during the Tertiary epoch, and that the individual outbreaks had been separated by long intervals of time, during which fresh-water deposits, conglomerates, and even thin coal-seams had accumulated. The volcanic flows covered considerable areas and solidified quickly into compact basalt, sometimes to spheroidal or columnar basalt. Forbes had already expressed the opinion that in Scotland it was not a question of submarine but of subaerial eruptions, and Sir Archibald Geikie confirmed this view.

While Geikie was still engaged in his field investigations, Professor Judd published a paper on the extinct volcanoes of the Scottish Highlands, in which he tried to prove that the volcanic outbursts had proceeded from five great central volcanoes. Judd supposes three periods of eruption, the first characterised only by acid rocks (felspathic lavas and granite), the second by basalt and basaltic tuff, and the third by the formation of sporadic volcanic cones of various constitution. Geikie contested these views in a series of papers whose contents are comprised in the second volume of his work, *The Ancient Volcanoes of Great Britain*, published in 1897.

No basaltic region in the world has been examined and described with the same accuracy as the Western Isles of Scotland. Sir Archibald Geikie has convincingly proved the order of succession of the different contemporaneous flows, the age of the various intrusive sheets and dykes, the occurrences of fossiliferous strata interbedded between the contemporaneous basaltic flows, and has also demonstrated the presence of ancient necks and in several places even vestiges of original craters on the surface of the older lavas. Through his exposition of one of the most involved and puzzling pieces of research undertaken in any country, Geikie has thrown new light upon the history of extinct volcanic action. In his hands this typical district of ancient volcanicity has revealed to the geologist many fundamental principles of correlation in the subterranean and surface distribution, and in the consolidation of rock-magmas, which are of the highest significance for the study of homogeneous volcanic rock. The diverse and often marvellously beautiful scenic effects produced in the

volcanic rocks by subsequent denudation have been treated with no less careful observation and insight.

In the course of his researches, Geikie did not confine himself to the Scottish volcanoes of Tertiary age. The first volume of his important work treats the older volcanic rocks of Great Britain from the Pre-Cambrian to the close of the Permian period. Geikie does not admit any essential difference between old and modern volcanoes, and he judges all massive outpourings, sills and dykes, homogeneous bosses and cones, from this standpoint. On the one hand, the phenomena of past periods are read in the light of recent manifestations of volcanic action; and *vice versâ*, the stratigraphical relations of the submarine tuffs and massive outbreaks of the Palæozoic era are used to elucidate certain of the recent phenomena which are removed from present observation. In this volume, examples are described of typical stratified volcanoes in the Silurian and Devonian formations of Wales and Scotland, the extensive fissure-eruptions of the Carboniferous epoch in Scotland, and the scattered homogeneous domes or tuff-cones which took origin in England during the same epoch. In the Mesozoic period, Great Britain was marked by almost complete cessation of volcanic activity.

The volcanic phenomena of the Faröe Islands have been investigated by Professor James Geikie (1880), Amund Helland (1881), Bréon (1884), and Lomas (1895). These islands display a close relationship with the northern areas of Great Britain.

Important contributions to our knowledge of volcanicity have been made by Dr. Hermann Abich, in his works on the geology of the Caucasian areas. The Persian volcano Demavend has also been made the subject of geological researches, the Austrian geologist, Dr Tietze, having given the most recent account in 1878. Reports of the extinct volcanoes of Asia Minor appear in several books of travel published about the middle of the nineteenth century; the volcanoes in the vicinity of the Dead Sea have been examined in some detail by Blanckenhorn and Diener.

In Asia proper, volcanic activity is at present concentrated along the eastern coast-line, on the borders of the Pacific Ocean. The volcanoes in Kamtschatka, in the Aleutian and Kurile Isles, in Japan, Formosa, and the Philippines, have been repeatedly described in geographical and geological litera-

ture. More special geological papers on the volcanoes of Japan have been published by Naumann in Germany, by Milne in England, and by Wada and other Japanese authors in the scientific literature of Japan.

Junghuhn's well-illustrated account of the Javanese volcanoes holds a distinguished place in the literature, and the pioneer work of investigation begun by German explorers was ably continued by the later communications of Emil Stöhr on the Idjen-Raun and the Tenggor volcanoes in East Java, and by R. D. M. Verbeek, on the volcanic outbursts which culminated in the fearful catastrophe of the Krakatoa eruption in 1884.

India, although unvisited by recent volcanic action, was the scene of colossal outpourings of volcanic matter during the Cretaceous epoch. The Geological Survey of India has already made known the leading characteristics of the Deccan basalts and tuffs which extend throughout a vast territory in the heart of India.

A classical district for volcanic research is the island of Hawaii with the two giant-cones Mauna-Loa and Mauna Kea. These were described in 1840 by Professor Dana, and in 1884 a detailed monograph on the Hawaiian volcanoes was published by Clarence Edward Dutton. Charles Darwin's "Geological Observations on the Volcanic Islands visited during the voyage of H.M.S. Beagle" (1844) laid the foundation for a new field of volcanic research; and the geological results of the *Challenger* Expedition have contributed materially to the scientific knowledge of submarine eruptions.

The African continental volcanoes, notably the Kamerun in the west, the Kilimandjaro and Kenia in the east, and the Ruwenzori in the interior, are remarkable for their great size. They have been frequently ascended during the last decade, and the rocks have been partially investigated, but so far their investigation has not contributed much that is new in volcanic research. The extensive outpourings of volcanic material in Eastern Equatorial Africa are stated to have begun after the close of the Jurassic period.

North America possesses active volcanoes only in the extreme north-west, in Alaska and Washington territory. These have been described by the geologists of the United States; detailed information having already been given of all the important areas, Mount Elias in Alaska, Mount Rainier (Tacoma) and Mount Hood in the Cascade mountains, and

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the Mono Valley in East California. The magnificent basalt plateau in Oregon and Washington, through which the Columbia River has channeled its course, was made known to the scientific world by Hayden, and the same geologist described for the first time in 1871 the wonderful lava plateau in North-Western Wyoming, on the banks of the Yellowstone River, with geysers, hot springs, mud volcanoes, and extinct volcanic hills. Since the Yellowstone Park became in 1872 the national property of the United States, the Geological Survey Department has carried on without intermission the work of scientific exploration and detailed research in this region. Professor Iddings has described the volcanic rocks of the National Park in two memorable reports of the United States Survey (1888 and 1889).

Farther south, the high table-lands of Colorado, Arizona, and New Mexico display a number of extinct volcanoes which have broken through horizontal strata of Palæozoic age and repose upon them as widespread sheets or conical hills. The volcanoes in Southern Colorado and in Arizona were described by Powell, Wheeler, King, Gilbert, and others, and in 1882 the United States Survey published Dutton's admirable monograph of the Grand Cañon district.

The Henry mountains, in the greatly denuded region west of the Colorado River, will always be memorable in geology as the locality of Gilbert's epoch-making researches on volcanic rocks. Gilbert demonstrated there the true nature of certain deep-seated intrusions which had made their way mainly along the bedding-planes of sedimentary strata, had solidified there in cistern-like form, and displaced the surrounding beds by their pressure. Such intrusions were termed "laccolites" by Gilbert, and in so far as they exert uplifting forces on the strata above them, Gilbert's laccolitic intrusions are reminiscent of Von Buch's Elevation-Craters. The term of "laccolite," together with Gilbert's explanation, is almost universally accepted by geologists. Peale, Holmes, and Endlich (1877) have shown how, in virtue of denudation and removal of the stratified rock-material, individual laccolites have been exposed superficially as dome shaped bosses of igneous rock.

Alexander von Humboldt was the first to explore the Mexican volcanoes, and the German geologists Felix and Lenk published, during the years 1888-91, valuable contributions to the geology and palæontology of Mexico. The volcanoes

of Guatemala and San Salvador were described in 1868 by M. Dollfuss-Montserrat, and Dr. Sapper has recently been engaged on a series of researches in this area.

There have been comparatively few geological publications dealing with the volcanoes and volcanic rocks of South America since the pioneer works of Humbôldt. Dr. Alphons Stübel has, however, made a special study of the volcanic mountains of Ecuador, and published in Berlin in 1897 a special monograph of the district, accompanied by a Geological Map. Dr. Stübel gives a summary of his results in the introductory chapter, where he represents his views on volcanic phenomena from a general standpoint. He thinks it probable that in the first stage of the Earth's cooling, outpourings of magma occurred so frequently, and were of such colossal dimensions that the older volcanic material had only partially solidified when younger outflows burst forth and spread above them. In this way the cooling of the older magmas was indefinitely delayed, and they continued as local "peripheral" cisterns or reservoirs of volcanic material, occurring at very small depths below the surface, and extremely sensitive to any variation in the surrounding physical conditions. Dr. Stübel regards these "peripheral" reservoirs as the base of supply from which present volcanoes derive their volcanic material, and he correlates the surface extent of volcanic groups and the arrangement of the individual eruptive vents or fissures with the original shape and size of the respective areas of primitive, uncooled magma. The force which enables it to rise again to the surface resides, according to Dr. Stübel, in the magma itself, and the region of the least resistance is the path along which the liquid masses find their way to the surface. The conditions of least resistance, he adds, are most commonly met with at the limits of different kinds of rock.

The scientific study of the extinct volcanoes, and especially the exact petrographical examination of the products of eruption, has exerted a marked influence on the theoretical explanation of volcanic phenomena. It was only to be expected that exact knowledge should finally dispose of many fanciful hypotheses, such as those which explained volcanic action from the burning of coal-seams or petroleum, the decomposition of sulphur metals and other substances, from electricity, or the local disengagement of vapours.

Wider geographical and geological knowledge has shown the earth's volcanicity to be a phenomenon of universal occurrence which cannot be explained as a result of occasional local catastrophes.

Descartes had in 1644 suggested that the friction of inthrown rock-masses might induce processes of fusion, and Franke in 1756 attributed volcanic outbreaks to local shearing in the earth's crust. More recently, conversion of mechanical work into heat was made the basis of a hypothesis by Volger in his book entitled *The Earth and Eternity*, published in 1857. Volger suggested that both earthquakes and volcanoes were caused by partial collapse and inthrow of rock-material superincumbent upon subterranean cavities. A mechanical theory of a somewhat different character was proposed in 1866 by Mohr. He supposes that certain deep-lying strata in the earth's crust have lost their original consistency either by means of chemical decomposition or from other causes. If these weaker layers be subjected to the pressure of a considerable thickness of overlying rock-deposits, and if, as in the submarine areas, they have to bear in addition the weight of a vast column of water, they may be crushed, heated, and even in some cases melted and ejected at lines of crust-fissures. Mohr referred more particularly the submarine tuffs to this mode of origin. Pfaff wrote in 1871 a paper on "Volcanic Phenomena," in which he opposed Mohr's theory, and said that thermo-dynamic action alone could not generate sufficient heat to fuse rock-masses.

The English physicist, Robert Mallet, made the most successful attempt to found a mechanical theory of volcanicity. He assumed that the earth's crust, in consequence of a slow and protracted cooling of the globe, is now of considerable thickness. During the earth's cooling the masses contracted as they solidified, and their contraction created tangential pressures through the crust. According to Mallet's theory, the hotter internal mass of the earth cools and contracts more rapidly than the crust, which is in consequence liable to recurring accidents of incrush and inthrow. Tangential pressure is resolved into vertically-acting forces, and folds and corrugates the earth's crust, forming larger and smaller mountain-chains. Fissures develop along the lines of greatest weakness in the crust, and it is chiefly at these that the rocks give way for long distances and are crushed and

crumpled. The work effected by the compression and movement of the rocks is transmuted into heat, and under local conditions of concentration of the movements or sudden cessation and relief of pressure, the temperature of the crushed rocks may arrive at the point of actual fusion. If interstitial or descending surface-water be absorbed by the glowing rock-masses in sufficient quantity, its conversion into steam at any moment of diminished pressure may give origin to explosive volcanic phenomena at the surface. These are the general arguments in Mallet's theory of volcanicity, which was strengthened by the author's elaborate series of experimental researches on the stresses required to crush different varieties of rock, and the amount of heat that would be produced in each case by this mechanical means.

Mallet's theory has been contested by Justus Roth in Germany and by Poulett-Scrope and Fisher in England. But certain ideas in it, such as the steady contraction of the earth's nucleus and its tendency to shrink away from an unequally yielding crust, have proved distinctly valuable in the consideration of the earth's physics, and have been variously applied by later authors.

Most geologists at present look sceptically upon any theory which derives volcanic action from the conversion of dynamical energy into heat during crust-movements. Present opinion associates volcanic phenomena with the primitive internal heat of the earth, and supposes rock-magma to be embodied in a state of fusion within the earth's mass. This was likewise the broad conception of volcanicity which was held by the ancient philosophers, and by Athanasius Kircher, Steno, Buffon, Dolomieu, Spallanzani, Faujas de Saint-Fond, Von Humboldt, Von Buch, Poulett-Scrope, Daubeny, and Lyell.

The actual protrusion of subterrestrial magmas into the earth's crust or at the surface was attributed by Cordier, Constant Prévost, and Dana to the cooling of the earth's crust and the pressure which it therefore exerts upon the nuclear mass. Professor Suess has applied the distinctive term of "batholite" to an older massive protrusion of magma solidified as coarse crystalline rock in the deep horizons of the crust. In 1888, the same geologist in his famous work, *Der Antlitz der Erde*, discusses the conditions which determine the particular form of igneous protrusion, whether as deep-

seated batholites, as laccolites intruded at various horizons between the sedimentary deposits, as fissure eruptions, or volcanic explosions. He summarises his views in the following sentences: "The uppermost peripheral parts of the earth's body are held firmly arched in virtue of the tangential tensions. Either radial tensions or crust sagging causes a part of the earth's body to split away from the outer crust towards the interior, and a large cavity or macula forms more or less parallel with the earth's surface, lenticular in shape if produced mainly by sagging, and wider if due to radial fracture. The macula fills with lava; and if the surface rocks subjected to tangential tensions find escape from them in any direction, for instance by a folding movement or by the overthrust of another mass of rock, then the relieved portion of the arched crust which is immediately above the macula sinks into it and lava wells forth at the faults and deeper inthrows" (*loc. cit.*, vol. i., p. 220).

Dr. Reyer, in his work *Theoretische Geologie* (1888), groups batholites, laccolites, domes (Kuppen), and sheets as massive eruptions, and distinguishes them from true volcanic eruptions associated with fragmentary discharges. At the same time he allows that in Mexico, Iceland, and in other localities, massive intrusions and outpourings occur in combination with typical tuff volcanoes. Reyer contests Gilbert's explanation of laccolites as intrusions following the bedding-planes of strata; he regards them primarily as surface protrusions contemporaneous with the sedimentary deposits in association with which they occur; and with regard to the apophyses extending from laccolitic invasions into superincumbent strata, Reyer says they are intrusions altogether subsequent to the laccolites. True volcanic mountains must, according to Reyer, include tuffs and loose fragmental products, but may or may not include lava; these are piled round the orifice and arranged as inclined successive layers. The craters are, he thinks, usually the result of explosion; occasionally, however, they arise from inthrow. The larger areas of subsidence, on which the volcanic mountains are found, appear to have been formed by repeated eruptions.

It had been recognised by Dolomieu and Spallanzani that the violent outbursts from active volcanoes could not be entirely due to the pressure of the outer firm envelope of the earth upon internal molten material. But, whereas Dolomieu

suggested sulphur as the cause of fluxion, Spallanzani believed that the expansion of vapours was the main cause of the explosive phenomena of eruptions, and Humboldt and Poulett-Scrope accepted and extended Spallanzani's view. Scrope regarded the elastic vapours as original constituents of the earth-magma; on the other hand, Humboldt contended that water had passed down from the surface through fissures, had there come in contact with the glowing magma, been converted into steam, and absorbed in the magma. The majority of later geologists agree with Humboldt's explanation.

Humboldt had chiefly in view the descent of sea-water through crust-fissures, as the geographical distribution of active volcanoes would suggest, but he by no means excluded the likelihood that similar results ensue from the percolation of meteoric water through the rocks. The obvious difficulty, pointed out by Humboldt himself, was whether the hydrostatic pressure of the descending column of water could overcome the resistance of the vapours at high tension in the earth's interior. Bischof and Daubrée have shown that surface water may, in virtue of capillarity and the pressure of its own column, descend into the heated depths of the earth. Angelot also concluded that the tension of a column of water would at any depth be overcome by the pressure of the superincumbent masses of water; in his opinion, the ocean is the source of the vapours dissolved in deep-seated magma. And Bischof shows that not only water-vapour but also carbonic acid, hydrochloric acid, and other gases imprisoned in rock-magma play a considerable part in eruption.

In more recent geological writings, Reyer has investigated the question of supply in reference to the constituents of molten magmas, and his conclusions are in agreement with those of Angelot, Fourier, and Poulett-Scrope. According to Reyer, at the formation of the earth, not only vapour of water, but many other gases and liquids were intermixed with the material matter of the earth, and these have been preserved in it. The continual separation of the less fusible parts from the magma is always accompanied by the escape of gases. These are absorbed by the liquids with which the magmas are soaked, and owing to a relief of superincumbent pressure, the liquids may at any time vaporise and the magma may be expelled towards the surface in fluid condition. Experiments

were made by Hochstetter, Suess, and Reyer on molten sulphur and other substances which absorb gases in large quantities, and during the process of cooling from the molten condition, the escape of the gases was accompanied by explosive phenomena. Under certain circumstances, at the places of explosion conical-shaped masses formed resembling those of volcanic mountains.

F. *Earthquakes.*—Earthquakes may arise in the solid crust or in still deeper horizons of the earth. They accompany all the more violent eruptions, but they may take place quite independently of volcanic phenomena. Records of earthquakes have been handed down from the earliest times, but the classical and mediæval writers confined themselves to the descriptions of the leading natural phenomena, and the catastrophes and terrifying effects produced by earthquakes on people and animals.[1]

Scientific research of earth-tremors may be said to have commenced in the beginning of the eighteenth century, and had already progressed so far that Hoff was able to compile an excellent monograph of earthquakes for the second volume of his work. Another good account of the phenomena and effects of earthquakes was published in Friedrich Hoffmann's posthumous works (1828). An essay by Dr. Kries upon the origin of earthquakes was awarded a prize at Leipzig in 1827. Naumann's *Text-book of Geognosy* contained a complete *resumé* of all the scientific facts about earthquakes known before 1850. So exhaustive was Naumann's account that Landgrebe could bring forward little additional knowledge in his *Naturgeschichte der Vulkane und Erdbeben* (vol. ii., 1854).

All the earlier writings of the nineteenth century follow Alexander von Humboldt in representing earthquakes and volcanoes as different manifestations of the same set of causes. Humboldt defined earthquakes as "Reactions of the earth's nucleus against the solid crust," and volcanoes as "Safety-valves" for the immediate neighbourhood of such disturbances. Emil Kluge, who made a special study of the earth-tremors and shocks in the years 1850-57, supported Humboldt's

[1] A short historical account of the prevailing views regarding earthquakes which were held by the authorities of antiquity and the Middle Ages, will be found in R. Hoernes' *Erdbebenkunde*, Leipzig, 1893.

standpoint, and placed great importance on evidences of the interchangeable relations subsisting between earthquakes and volcanoes. Naumann contended, in opposition to Humboldt's generalisation, that certain earthquakes might be termed plutonic, in so far as they occurred independently of volcanic influences; Von Seebach also attributed earthquakes in some instances to local disturbances of crust-equilibrium, not necessarily associated with the earth's volcanicity. Since Humboldt's famous description of the Cumana earthquake, great advances have been made in the knowledge of the geographical distribution of earthquakes, the methods of determining the position of seismic foci, and the rate, the intensity, and the mode of propagation.

One of the most indefatigable bibliographers of earthquake phenomena was Professor Alexis Perrey in Dijon. Between the years 1841 and 1874 Perrey collected statistics of earthquakes extending back for more than fifteen centuries. In England, Robert Mallet and his son J. W. Mallet published an *Earthquake Catalogue* for the period 1606-1858; Muschketow collected the data of the Russian and Central Asiatic earthquakes; in Germany, Hoff and Berghaus published in 1841 a catalogue of volcanic eruptions and earthquakes, and C. W. Fuchs kept a regular chronicle of observations from 1873 to 1885; Volger published a careful account of the Swiss earthquakes, together with some notes on the periodicity, propagation, and extension of the shocks.

Italy, so frequently the scene of destructive earthquakes, possesses in De Rossi, the founder of "underground meteorology," a historian of equal rank with Perrey. De Rossi's chief work, published 1879-82, comprises his own valuable observations and regular records kept for several decades in the seismological observatory which he erected at Rocca di Papa in the Alban mountains.

Baratta carefully compiled all the records of the terrible earthquake in the year 1627, which devastated the peninsular area of Monte Gargano. The Neapolitan earthquake of 1857 was recorded in a masterly and suggestive paper by Mallet. The violent shocks during the last decades of the nineteenth century at Belluno (1873), Ischia (1883), and Liguria (1887), have been made the subject of a large number of publications by foreign geologists and meteorologists. A

voluminous literature now exists on earthquakes and slight tremors experienced in Europe during the last quarter of the nineteenth century, special commissions having been appointed in most countries to keep a record of observations.

In Great Britain, Professor James Geikie, Davison, and White continue the work of R. and J. W. Mallet, and there is no lack of observations in North America, Guatemala, Mexico, India, Australia, and Africa. Seismological studies were initiated by Dr. E. Naumann and Dr. Knipping in Japan, and the newer reports of Dr. Milne, Koto, Sekiya, and others in the *Transactions of the Seismological Society of Japan*, contain full accounts of the earthquakes in these localities.

Of late years very delicate seismometers have been invented, by the use of which it has been possible to obtain accurate records, not only of violent shocks but of finer pulsations and tremors imperceptible to human sensation. Cacciatore of Palmero used as a seismometer a shallow shell filled with quicksilver, and having a number of notches at regular distances round the edge; small cups were placed below the notches, and in the event of any movement of the shell, the quicksilver escaped into these cups and could be weighed as a measure of the intensity of the shock. This simple apparatus was replaced by numerous others of much more complicated construction, which sometimes applied the pendulum, and were sometimes made self-registering by specially devised clock-work. Thanks to many ingenious inventions, meteorological science now possesses a wealth of observations on the frequency, continuance, periodic recurrence, and geographical distribution of earthquakes, as well as on the mode of transmission, direction, intensity, rate of propagation, and character of the shocks. Geologists have concerned themselves more with the destructive effect, the surface deformation and geological action of crust-tremors, and with the modifying influence exerted by the various kinds of rock upon the intensity and transmission of earth-movements.

Mallet, Von Seebach, Von Lasaulx, and Dutton proposed various methods of ascertaining the area of impulses during an earthquake. Both Mallet and Seebach concluded from geometrical methods that the seismic focus was at a comparatively small depth below the surface, but this result, so far from having been confirmed, seems to be contradicted by

Whitney's observations in California, by Wynne's in the Punjab, and by Heim's in Switzerland.

Perrey's long historical catalogue of earthquakes was intended in the first instance to determine how far earth-tremors had been encouraged by the particular times of the day, or seasons of the year, or by the disposition of the earth with reference to other heavenly bodies. The results are not altogether satisfactory, for although they prove greater frequency of earth-tremors in winter and autumn than in other seasons, no definite law can be induced. Neither do the statistics give any confirmation of the idea that the occurrence of earthquakes may have some connection with meteorological conditions. On the other hand, they led Professor Perrey to conclude that an explanation of earthquakes might be found in the varying attraction of the moon at its different phases.

He supposes the earth's crust to be as uneven on its inner concave surface towards the nucleus as upon its outer surface; that under the attraction of the moon the hot nucleus swells upward in wave-like form and presses against the weakest parts of the crust, with the result that the terrene impulse is transmitted through the crust as an earthquake.

Dr. Rudolf Falb in 1869 independently formulated a theory of earthquakes similar in character, but more fully elaborated than that of Professor Perrey. Dr. Falb connects high tidal waves of the earth's magma with the attractions exerted upon the earth by the sun, the moon, and other heavenly bodies, and he therefore thinks it possible to foretell from astronomical calculations "critical" days or periods on which violent seismic disturbances will take place. A general connection between solar and lunar attraction and the occurrence of earthquakes is accepted by a considerable number of astronomers and geologists, amongst others, by J. Schmidt, C. F. Naumann, Von Lasaulx, Pilar, and others. But several authors have disputed Dr. Falb's theory. One main contention is the uncertainty regarding the actual condition of the earth's nucleus; many physicists and geologists now believe that the nucleus is practically solid, and that molten rock-magma can only be present under certain definite conditions of depth and pressure, and is necessarily of limited distribution in the earth's mass.

Friedrich Hoffmann had distinguished different kinds of

earthquakes according to their field of action as *successive* or vertical, *undulatory* or wave-like, and *rotatory* or whirled. At the present day, earthquakes are usually classified as central and linear; in the case of "central" earthquakes the undulatory movements radiate from a seismic focus towards all directions; in the case of "linear" earthquakes, the movements are limited to long strips of the crust. Von Seebach termed the subterranean origin of an earthquake the "seismic centre"; the median point at the surface within a region of earthquake shock he termed the "epicentrum"—at this point the shock manifesting itself chiefly by up and down motion; and to the imaginary lines drawn through all points simultaneously affected by the shock, he gave the name of "homoseisms" or "isoseisms." But it has to be remembered that a definite central point of origin has only been determined in a few cases. Generally the seismic centre or focus has been ascertained to be in point of fact an underground area from which concussions are propagated vertically along a large number of parallel lines, which Mallet has called "Seismic Verticals." Undulatory impulses are also transmitted obliquely through the surface, the intensity of the shock at the surface diminishing in proportion as the angle of emergence increases. In the case of the Agram earthquake in 1880, a large surface area was affected by vertical movements of almost equal intensity, showing that the underground focal area was of considerable extent.

The leading geological authorities now associate earthquake shocks with manifestations of volcanism, crust collapse, or tectonic crust-movement. Earthquakes as a rule precede or accompany the eruptions of active volcanoes, but they often occur in volcanic districts when there is no actual discharge from volcanic vents. The earthquakes which have been directly traced to crust subsidences were of small extent and intensity. And it is now widely accepted that most earthquakes which occur in non-volcanic districts are originated by dislocations and movements in the earth's crust.

In two suggestive papers (1873-74) on the Earthquakes of Lower Austria and Southern Italy, Professor Suess showed conclusively that earthquakes occur along the lines of tectonic movement in a mountain-system, and quite irrespective of any volcanic phenomena. Hoernes contributed several interesting papers on tectonic tremors, demonstrating by

specific examples the frequency of earthquakes along narrow tracts or over areas which haye been the seat of important crust-movements of displacement, fracture, or subsidence. Toula proposed the distinctive name of "dislocation earthquakes" to such as accompanied the grander movements in the earth's crust.

Gilbert in California, Griesbach in Beloochistan, Koto in Japan, and other observers have proved the origin of extensive fissures at the earth's surface as a consequence of recent earthquakes. Permanent changes in the surface conformation, especially subsidences, have very often been reported as a chief factor in the catastrophes caused by earthquakes. In the fearful earthquake at Lisbon, the quay sank into the sea with all the ships anchored in it and thousands of people on its margin. During the Calabrian earthquake, in the year 1783, more than two hundred lakes and morasses were formed. In the year 1819, according to Lyell, an earthquake at the eastern river-mouth of the Indus converted an area 2000 square miles in extent into a lake; on the Mississippi flats, in China, Syria, and Chili, earthquake inthrows have been recorded.

It has, however, rarely happened that the ground has been elevated in consequence of the passage of an earthquake. The best known accounts of elevations come from Chili, and were accepted as trustworthy by no less an authority than Charles Darwin; Professor Suess regards them as of doubtful integrity, and C. W. Fuchs affirms that since earthquakes and their phenomena and consequences have been observed with scientific accuracy, not a single case of ground-elevation has been authoritatively recorded.

G. *Secular Movements of Upheaval and Depression.*—The study of the sedimentary deposits of past geological epochs reveals conclusively that vast changes have repeatedly taken place in the distribution of land and sea upon the face of the earth. But it is difficult to determine what changes are now in progress, whether certain parts of the earth's land surfaces are being at present elevated or depressed, or whether oceanic variations are accomplishing changes in the relative level of land and sea. It seems almost impossible to record slow movements in the interior of the continents, and the topographical maps render little assistance in this respect, as

it is only a century since measurements of height have been taken in sufficient number and with sufficient accuracy to afford secure data for comparison. For geological processes a hundred years is a period of as small significance as a single second in the history of mankind.

It is easier to determine variations of level at sea-coasts, but even there it is often doubtful whether a change of relative level is due to displacements of the land or of the ocean; and the observer has to be careful not to mistake for secular movements any of the effects of sedimentation in heightening the land, or of marine erosion and subaerial denudation in breaking down the coast. The occurrence of submerged forests and beds of peat, old roads and other human structures on the sea-floor are among the more secure evidences of a depression of the land or uprise of the water. On the other hand, remains of harbour and pier constructions, and fragments of vessels found at a height above the existing sea-level, or at some distance inland, give evidence of a secular movement of land-elevation or retreat of the sea within historic ages. Former coast-lines and terraces can sometimes be identified many hundred feet above the present surface of the ocean. The exposure of delta deposits is usually regarded as a sign of land elevation, whereas long narrow fiords occurring as the continuation of river-valleys towards the sea, are regarded as proofs that a coast is undergoing subsidence.

The oldest direct observations on relative changes of level were made in Scandinavia. Hjärne observed in 1702 that the Swedish coasts were frequently extended in consequence of a retreat of the sea, and Celsius and Linnæus afterwards made investigations on the rate of retreat by means of boundaries and marks on the rocks at Gefle and Kalmar. Celsius in 1743 read his memorable paper at the Swedish Academy of Science, in which he argued that the volume of water in the ocean was diminishing. He calculated the sinking of the ocean surface-level at forty-five inches in a century. Linnæus supported the views of Celsius, but Bishop Browallius (1756), E. D. Runeberg, and the Danish scientist, Jessen (1763), opposed them. E. D. Runeberg argued that the changes on the Swedish coast were due to elevation of the land in consequence of earthquakes.

The Scottish mathematician, Professor Playfair, in 1802

raised an important objection to the theory of Celsius by pointing out that if the changes were really due to the lowering of the ocean-surface, the diminution should, according to hydrostatic laws, take place quite uniformly, and this was apparently not the case. Playfair therefore attributed the changes to an elevation of the land in consequence of subterranean forces. Leopold von Buch also formed the opinion that the Swedish coasts were rising, but neither in his work in 1807, nor in Karl von Hoff's historical and critical reviews in 1834, was any explanation suggested as to the causes of the movements.

The Stockholm Academy appointed a Commission to inquire into all the evidences, and the reports in 1820 and 1821 entirely corroborated the scientific account of a general extension of large coastal tracts. The upraised mussel-beds near Uddewalla, on the west coast of Sweden, and the raised beaches with marine shells in Norway, had been cited by Buch, Brongniart, and Lyell as proofs of land elevation. Yet the chemist, Professor Jacob Berzelius, in 1835 adhered to the older view; he connected the changes along the coast with sinking of the sea-level in consequence of the cooling of the earth and contraction of the crust. In 1837, Professor Keilhau in Christiania collected all the observations that had been made on coast movement in Norway, and calculated from them that the land had risen 470 to 600 feet since the Diluvial epoch.

A French expedition was sent to Scandinavia and Lapland, and Dr. E. Robert, the geologist attached to it, was enabled to add to Keilhau's summary a number of supplementary observations in Finland and Lapland. It was thus proved that raised beaches and terraces extended throughout all the northern part of Scandinavia. Bravais, another member of the French expedition during a prolonged stay in Finland, followed the remains of former coast-lines between the Alten Fjord and Hammerfest, and in his papers published 1842-43 he described in the Alten Fjord two successive terraces which were not parallel with one another, but converged towards the coast and showed several variations of height at their different parts. This observation was declared by Naumann in his text-book to be incontestable proof that the coast had been elevated. Considerable doubt, however, was thrown upon Bravais's observations a few years later by Robert Chambers

in an important work on *Ancient Sea-Margins.* The Christiania Professor, Theodore Kjerulf, in 1871-73 also questioned some of Bravais's observations, although he in no way dissented from the opinion that the land had been elevated. Professor Sexe in Christiania sought an explanation of the phenomena in glacial action, but H. Mohn and K. Pettersen in several papers published between 1870 and 1880 refuted this suggestion, and added many new data in confirmation of land elevation. Dr. Pettersen showed that the Norwegian raised beaches and terraces occurred at higher and higher levels the farther inland they were found, and that the highest platforms were situated at the upper end of the deep fjords.

The Swedish geologist, De Geer, confirmed this observation both in Norway and Sweden, and drew up a chart of curves connecting all the raised beaches of the same height. These curves he termed "iso-anabases," and found that they formed a series of ellipses whose major axis almost coincided with the watershed between Sweden and Norway. De Geer concluded that Scandinavia had been slowly upheaved since the Ice Age, the extent of the upheaval exceeding 600 feet in the central areas of the country. But he thought certain facts indicated that there had been a slight movement of subsidence between a period of maximum upheaval and the present epoch of elevation. While it was in Scandinavia that crust movements now in progress first attracted the attention of scientific men, keen interest was aroused in Scotland by analogous examples of upraised mussel-beds and beaches (the "parallel roads"). As early as 1806, Jameson had observed deposits containing the shells of recent molluscs at some height on the shores of the Firth of Forth and the Firth of Clyde, but published no account of them until 1835. Afterwards several geologists examined them, amongst others Prestwich and Robert Chambers. The traces of ancient sea-margins far inland were first recognised by MacCulloch, and have since been described by Charles Darwin, Agassiz the elder, Murchison, Buckland, Lyell, and more recently by J. Geikie. Almost without exception all observers agree in regarding them as proof of recent elevation of the land.

Similar evidences of elevation occur in Ireland, England, Finland, on the coast of the White Sea, on the islands of Spitzbergen and Novaia Zemblia, on the coasts of Siberia, Greenland, on the eastern and western coasts of North

America, in Patagonia, the Argentine Republic, Chili and Peru, and at the southern extremities of Australia and Africa.

Darwin, in founding his Coral-reef theory, assumed that a slow subsidence had taken place over a vast region of the Pacific and Indian Oceans. In spite of a very large number of data, however, it has not been possible to formulate any definite law of secular variations. Movements of elevation and depression are reported in various latitudes, and are frequently known to take place in opposite senses at localities adjacent to one another. When Dana in 1849, from his observations in the Pacific Ocean, concluded that elevation was in progress in the region around the North Pole, and subsidence in the areas near the Equator, he formed his opinion upon insufficient data. The general truth has, however, been established, that relative changes of level are still in progress along many of the coast-lines, and that since the Diluvial epoch dislocations have been produced, measuring 300-1500 feet. In many cases these movements are slowly and imperceptibly accomplished, in others they occur with convulsive suddenness. Sartorius von Waltershausen in 1845 distinguished the former as *Secular*, the latter as *Instantaneous* fluctuations of ground-level.

Von Humboldt and Von Buch had directed attention to local movements of land in connection with volcanoes and earthquakes, and the example of this character most frequently cited in literature is the temple of Serapis at Pozzuoli, in the Bay of Naples. The columns of the ruined portico are marked by the borings of a marine mollusc at a height of thirteen feet above the present surface-level of the Bay. In 1803, Breislak in the French edition of his text-book explained the phenomenon on the hypothesis that the Serapeum had subsided and had remained for a period stationary at the water-level indicated on the pillars by the mollusc borings, but that afterwards a period of emergence and uprise had succeeded. This explanation was strongly opposed by Wolfgang von Goethe. The great poet would not listen to any arguments in favour of oscillations of level; in his opinion, the former submersion of the temple had been due to an enormous flood. Breislak's view has, however, been supported by several leading British scientists, Babbage, Forbes, Poulett-Scrope, and Charles Lyell. The excellent treatise published by

Babbage in 1834 has proved a reference work of permanent value. Lyell used it freely for his discussion of the subject in his *Principles*. Continental authors of repute, Hoffmann (1833), Scacchi (1849), also accepted the explanation of alternating movements, and the Serapeum became a recognised example in the text-books of "instantaneous" change of level.

Antonio Niccolini made observations for several decades, and wrote, between 1838 and 1846, a series of papers in which he contended that the submersion of the Serapeum had not been due to any movement of the land, but to a rise in the water-level of the ocean. Professor Suess has arrived at the same conclusion as Niccolini; he points out that the changes of level at Pozzuoli were limited to the area of the Phlegrean volcanic cones, and argues that after a slow rise of the water-level throughout many centuries, there came during, or immediately after, the eruption which formed Monte Nuove (1538), a sudden lowering of the water-level, so that the temple ruins were once more fully exposed.

Other cases of instantaneous uprise have been reported from the western coast of South America. The first account appeared in a letter from a lady, Mrs. Maria Graham, to the Geological Society of London. The letter relates how, after the Valparaiso earthquake in November 1822, a long strip of the coast of Chili rose three or four feet above the sea-level. The German traveller, Pöppig, heard confirmatory evidence from the fishermen of the district when he visited the Bay of Concon in 1827. Charles Darwin and Captain Fitzroy witnessed, in 1835, a violent earthquake in Chili, and they reported local elevations of eight or nine feet along dislocations that formed in the district of Concepcion and Valdivia. Darwin also observed raised beaches and terraces at various heights on the coasts of Chili, some of them 1,500 feet above sea-level, and he came to the conclusion that sudden elevations of land had followed the earthquakes so frequently associated with volcanic activity in that neighbourhood. Upon the basis of his direct observations in Chili, Darwin founded his bold theory of the uprise of continents and mountain-systems by successive sudden elevations due to volcanic forces.

Ever since oscillations of level have been observed, there have been differences of opinion regarding the cause or causes. Strabo doubted as little in the elevation of islands, mountains,

and portions of the continents, as in the collapse and submergence of larger and smaller areas of the land. Athanasius Kircher gave circumstantial descriptions of sunken islands (Atlantis), and of lands raised from the ocean-floor. In the eighteenth century, De Maillet and Buffon ascribed changes of surface conformation to gradual diminution of the ocean volume, while Lazzaro Moro tried to explain the double aspect of emergence of land and ascent of the water-level by means of volcanic catastrophes. The Swiss investigator, J. G. Sulzer, in 1746 suggested the possibility that the position of the earth's centre of gravity was affected by the variable distribution of surface material; and Justi, in 1771, believed in "wanderings" of the Pole.

In 1702, the Swedish physicist Hjärne had introduced the method of direct observation by having marks hewn on the rocks of the coast, and thus paved the way for the definite knowledge obtained in the case of the Scandinavian movements. Scientific opinion then wavered between two chief parties, the one believing with Celsius in the lowering of the ocean-level; and the other and stronger party following Hutton, Playfair, Buch, Lyell, and others in ascribing the relative changes of level to upheaval of the land associated with subterranean volcanicity. Bischof, although he expressed in the chapter on "Heat" his agreement with the Huttonian Theory of Expansion, afterwards attributed secular movements more especially to alternating expansion and diminution of volume produced in deep-seated rocks by chemical transformations. Following this direction of thought, Volger, Mohr, and Vogt thought that the originally sedimentary rocks of Scandinavia had been transformed into crystalline rock, and had undergone an expansion of volume during the process of crystallisation.

The French mathematician, Adhémar, was the first scientist who, in seeking an explanation for crust-movement, considered the earth in its cosmogenetic relations. He regarded the influence of the earth's internal heat as quite irrelevant to the climatic conditions at the earth's surface; these he attributed wholly to the action of the sun's heat, and investigated the varying positions of the earth relatively to the sun, with a view to explaining the recurrence of Ice Ages and also the associated periodic rise and retreat of the ocean. Research in this direction thirty years later was greatly advanced by James

Croll and J. H. Schmick. These observers also supposed that periodic attraction of the ocean-water now towards one hemisphere, now towards the other, caused variations of climate and fluctuations of level. But if this hypothesis be correct, there ought to be extensive regions of depression or elevation; local movements in opposite senses, and especially oscillatory movements, are excluded. Dana's assumption of a widely-extended movement of elevation towards the North Pole has been supported by Sir Henry Howorth, whose idea is that the land is rising at both the Poles and contracting at the Equator.

From the actual distribution of the geological formations, Dr. Trautschold inferred the probable conditions of the earth's surface during past epochs, and argued that the volume of water in the ocean has gradually been diminishing. As immediate causes of diminution, he specified the accumulation of masses of snow and ice on land areas, the formation of inland seas and rivers, the absorption of water in consequence of the hydration of rock-forming minerals, and the consumption of water in the organic world. Dr. Trautschold by no means contested movements of crust-elevation, but thought many cases of so-called secular upheaval explicable by the lowering of the ocean-level.

Professor Eduard Suess introduced quite new ideas into the discussion of secular movements. In 1875, in his work on the origin of the Alps, he attributed the elevation of the Scandinavian Peninsula to the upward arching of a wide fold; but in later works, when he entered into a full and critical treatment of the whole question, he came to the conclusion that there were no movements of the crust in vertical senses, with the exception of those which are accomplished indirectly in the course of crust-folding. Suess then proposed a neutral terminology to express changes of level; instead of "elevation" and "subsidence" he now speaks of "positive" movements when a coast-line *appears* to rise, and "negative" movements when it *appears* to sink. His first elucidation of these views in 1880 culminated in the statement that the phenomena of so-called secular upheaval and depression had their origin in continuous changes in the liquid envelope of our globe. Suess could offer no explanation of those changes, which sometimes at one period might amass the ocean-water towards the equatorial zones, at another withdraw it towards Polar regions. He indicated as a possibility that they might have some connection

with variations in the earth's rotatory force, and consequently in the length of day and night, or with any incongruity between the earth's centre of gravity and the centre of form.

Professor Penck agrees with Suess in the leading principle that secular variations are due, not to crust-movements, but to fluctuations of sea-level. He doubts, however, the possibility of the equilibrium between land and water being disturbed by general variations of the earth's gravity. He traces all changes of level in maritime tracts of land to local re-distribution of rock-material and consequent local alteration in the attractive force exerted by the land upon the water-surface. Re-distribution may be produced by crust-folding, by the denudation of adjoining continental areas by the sedimentation of organic and inorganic deposits on the sea-floor, and most of all, in Professor Penck's opinion, by the piling-up of colossal masses of ice in particular regions. The American geologist, Mr. Upham, has arrived, on independent grounds, at similar conceptions of variation in the sea-level, although he at the same time believes in the actual upheaval of land areas.

The whole question is again discussed by Suess in the second volume of his work, *Das Antlitz der Erde*. This volume describes and compares the coast-line of the Atlantic and Pacific Oceans, passes in review the distribution of the oceans in all past geological epochs, and gives a complete account of all relative changes of level between land and water within historic time. The many sources of error and the insufficiency of data are noted; and the several causes which might have influenced the surface of the ocean are carefully elucidated. Professor Suess adheres firmly to his view that secular movements of elevation of land have been without significance in determining the grander forms of the earth's surface, and take place at the present day very exceptionally, and only as local phenomena. He depicts a shrinking crust or lithosphere, which as it contracts carries with it the immense body of water on its surface. According to Suess, episodal crust-subsidences have determined the form and position of the ocean-basins at different epochs of the earth's history, and have been accompanied by the corresponding widely-extended negative movements of the ocean. The existing oceans represent areas whose subsidence may have occurred in various ages, and whose boundaries are marked by lines of crust-fracture. Bearing in view the vast extent and the uniformity of those

negative movements, Professor Suess thinks it impossible to explain them by local ground-elevations; they must be assigned to physical causes of universal significance.

In addition to the general movements of the water-surface, there have been oscillatory fluctuations of level limited to smaller districts. Local sinking of level is probably due to submarine eruptions or any increase of the deposits on the sea-floor; or it may be connected with continental denudation and the smaller attractive power exerted on the water by adjoining land. Ascending movements have their origin probably in periodic and alternate heaping of the ocean-water at the Poles or at the Equator, or in local expansion of the water surface under the attraction of newly-formed land or ice masses.

The tangential folding of the earth's crust, to which Suess attributes the origin of mountain-systems, exerts, in his opinion, only a small and indirect influence on the sea-level. The uprise of continents takes place only as a result of crust-inthrows and consequent depression of the sea-level. In the upraised land, as the gradients of rivers become greater, the transportation of sediment is likewise increased; enormous masses of material gather close to the coast, and the weight of these depresses the sea-floor, inducing further positive movement. All the reported facts which might seem to countenance the conception of upheaval of the land are subjected by Professor Suess to careful criticism, and found by him to be for the most part untrustworthy as direct evidence of land movements. In so far as Suess has referred the grander secular movements to subsidence of the water-level associated with crust shrinkage, his results will commend themselves to all students of crust-physics. But his work cannot be said to have arrived at a solution of the causes of local oscillatory movements. Suess himself concludes his discussions with the somewhat mystic-sounding sentence:—"As Rama looks across the ocean of the universe, and sees its surface blend in the distant horizon with the dipping sky, and as he considers if indeed a path might be built far out into the almost immeasurable space, so we gaze over the ocean of the ages, but no sign of a shore shows itself to our view" (*Das Antlitz der Erde*, ii. 703).

Notwithstanding the strong arguments directed by Suess against secular upheaval of land areas, many geologists believe in an independent upward movement of certain parts of the

solid crust. Professor Erich von Drygalski, who as an explorer on the Northern Coast and in Polar regions is no less distinguished as a mathematical physicist than as a geologist and geographer, holds the opinion that phenomena of upheaval and subsidence can be produced by alternating decrease and increase of the temperature at the earth's surface. Professor Brückner, the chief Swiss authority on fluctuations of level, does not agree with Nordenankar and Suess that the positive movement of Scandinavia may be explained by the gradual depression of the Baltic Sea. On the German coasts of the Baltic, where the variations of the water-level, as in the case of inland seas, depend upon the amount of rainfall and the volume of inflowing river-water, the oscillations leave horizontal lines. But on the Swedish coasts the former coast-lines do not run horizontally, they slope obliquely upward, thus affording evidence, in Brückner's opinion, that the movement had been an unequal crust-movement. Several geologists who have more recently examined the Swedish coasts, Leonhard Holmström (1888), Sieger (1893), and Kayser (1893), arrived at the same result and supported the view of continental oscillations.

Penck has modified his previous opinion and now accepts independent crust-movement as a concomitant factor in elevating or depressing a coast-line. Brückner goes farther, he argues that all the present littoral displacements, which are not directly associated with volcanic activity at the surface, are explicable only if we accept crust-movement as an essential condition.

H. *Older Dislocations in the Earth's Crust—Tectonic Structure and Origin of the Continents and Mountain-Chains.*—The terrestrial movements and changes which have been observed within historic times give us but a faint indication of similar phenomena in earlier periods of the earth's history. On studying the dislocations which occurred in past geological epochs, we arrive at a clearer conception of consummated movements and their effects, we perceive how ancient strand displacements have culminated in the complete submersion of islands and continents, or in their emergence, and how mountain-systems have arisen in the neighbourhood of ancient zones of crust-disturbance and weakness.

With the exception of the observations of Steno, which were far in advance of his time (*ante*, p. 26), the scientific

and methodical investigation of the earth's crust may be said to have begun towards the end of the eighteenth century. The careful sections of the Thuringian district prepared by Lehmann and Füchsel initiated a new direction in crust-physics, and fore-shadowed the special work undertaken by stratigraphical research in the present day,—to find out the actual distribution of the rocks in the ground so far as they are at present exposed to view, and if they do not occur in undisturbed horizontal succession, to determine what displacements they have suffered, and reconstruct as nearly as possible a true mental picture of the sequence of events, the original distribution of the various sediments in time and place, the subsequent movements secular or paroxysmal, and the character of the resultant deformation of rock-particles and rock-masses.

Werner and his scholars contributed to field research many of its precise terms and methods. They examined the rocks with respect to strike and dip; alternations of strata; mutual stratigraphical relations in vertical and horizontal directions; the displacements effected along fault-lines; upheaval, curvature, bending and folding of rocks. The terminology which they applied very often betrays the close connection which existed between the mining industry and the beginnings of stratigraphy. The mines, the minerals, and any evidences of rock-displacement discovered during the mining operations were the sources of knowledge from which Werner taught, and as his scholars gradually extended their field of vision, and the glance of a Humboldt or a Leopold von Buch became world-wide, the early impressions and familiar terms of student days were grafted into the more ambitious conceptions and generalisations with which such men enriched the systematic study of the earth's crust. Many mining terms have thus been adopted into geological literature, although the original significance has been in some cases considerably modified.

Pallas and De Saussure gave the first more exact accounts of the structure of mountain-systems, and early in the nineteenth century important advances were made by the investigations of Ebel, Studer, Escher, Élie de Beaumont, and others in the Alps, those of Voigt and Heim in the Thuringian Forest, of Merian and Thurmann in the Swiss Jura Chain, of De la Beche in Cornwall and Devonshire, of Sedgwick and Murchison in Wales, and of the brothers Rogers in Pennsylvania. The

conceptions of geologists regarding the structure of mountain-systems altered as their knowledge of stratigraphy increased; the stages of progress may be judged by a comparison of the text-books of geology published in the successive decades of the nineteenth century.

The text-books of the Wernerian School were mostly ignorant of the complicated structure of mountain-systems; inclined strata were assumed to have originated in the inclined position. Their teaching on structure was based exclusively upon observations in plains, hill districts, and mines. Geological sections of mountains and plains appear in the work of Conybeare and Phillips, and an ideal section of the earth's crust in Buckland's *Text-book of Geology* (1836) became the model for a number of similar attempts. Lyell's *Principles* and *Elements of Geology*, like the majority of the text-books in the first half of the nineteenth century, treated the structural relations of the earth's crust somewhat meagrely. Naumann, in his *Lehrbuch der Geognosie* (1850), was the first author who devoted a special chapter to "Geo-Tectonics," and he comprised in it practically everything which had been established in this domain of geology.

As the interest in tectonical relations developed, the questions of the earth's configuration began to be studied from a more intelligent standpoint. Previous centuries had offered only speculative literary matter on this subject. Steno certainly had as early as 1669 appreciated the fundamental doctrines of configuration; upon the basis of his own researches in Tuscany, he had explained the forms of mountains and valleys as the results partly of crust compression and fracture, partly of the upheaval of stratified deposits, partly of the accumulation of volcanic material. Descartes, Leibnitz, and Buffon attributed the origin of ocean-basins, continents, and mountain-systems to fracture and wrinkling of the solid crust, and to withdrawal of the surface waters into subterranean cavities. Hooke, Vallisnieri, Lazzaro Moro, Needham, and others thought volcanic forces had upheaved the continents and mountain-systems.

Inthrows, subsidences, wrinkling of the crust in virtue of the earth's contraction, and upheaval by subterranean forces have long been recognised as the principal factors in determining surface conformation, and re-appear in modern theories with various modifications and applications.

The founder of the newer theories of upheaval was without doubt James Hutton, the Scottish geologist. According to Hutton, the earth's internal heat caused the rocks to expand and to find relief by bulging upward; thus portions of the earth's surface rose above sea-level and formed continents and mountains; volcanoes provided a means of exit for the hot vapours and molten masses of rocks, and prevented the excessive expansion and upheaval of the earth's crust. Although Hutton's theory of expansion and elevation was at first little considered, a number of observers like Fichtel and Pallas arrived at similar conclusions from independent researches, while De la Beche, Babbage, Lyell, and Poulett-Scrope accepted the theory and extended it in various directions.

Leopold von Buch was an enthusiastic supporter of the Huttonian theory. In the year 1812, J. L. Heim had assigned to basalt an important *rôle* in the elevation of mountain-chains. Von Buch ten years later, after his studies in South Tyrol, became convinced that the dolomite was an altered limestone, the transformation having been effected by the action of volcanic magnesian vapours during the protrusion of augite porphyry. From the stratigraphical relations of the sedimentary rocks and their association with the augite porphyry, Buch developed his well-known theory that the whole Alpine system followed the direction of an enormous fault, through which augite porphyry had locally escaped at the surface, and had elevated, tilted, and folded the neighbouring rocks. The results obtained in South Tyrol were then applied to Thuringia and the Harz, and finally the hypothesis was expressed that all mountain-chains had been upheaved by augite porphyry.

The disciples of Buch found in the theory of eruptivity and consequent disturbance of strata a complete explanation of all possible complications of crust-deformation, and for a time the upheaval of mountains was ranked as a volcanic phenomenon. Poulett-Scrope in 1825, in his work *On Volcanoes*, supported Hutton's Plutonic doctrine, and entered into an elaborate investigation of the ascent of intrusive granite and porphyritic masses in relation to the tectonical effects produced upon the different kinds of rock-strata which might happen to be in the neighbourhood.

A Swiss geologist of note who shared Buch's views on mountain-upheaval was Bernhardt Studer; he explained the

granitic and gneissose masses of rock in the highest chain of the Alps as the chief "centres of elevation" during Alpine upheaval, and applied to them the distinctive name of *Central Massives*.

Some remarks of Buch about the direction of the mountain-systems in Germany were destined to bear greater fruits than that thinker at the time realised. His paper *On the Geognostic Systems of Germany*, published in 1824, noted that four systems of strike had to be distinguished, the Netherlands or North-West system, the North-East system, the Rhine or North-South system, and the Alpine or East-West system. This observation of Buch gave the impulse to the works of a gifted French geologist.

Élie de Beaumont[1] belonged to the most enthusiastic adherents of the Volcanist doctrines. Many years of geological surveying in the Vosges and Ardennes mountains, in the mountains of Provence, in the Dauphiné and at Mont Blanc, had shaped in his mind new ideas about the origin of the mountains, and in 1829 he made these known in the *Annales* of the French Academy. Mountain-structure is discussed in

[1] Léonce Élie de Beaumont, born on the 25th September 1798, at Canon (Dép. Calvados), belonged to a noble family of Normandy. His preparatory studies were conducted in the Henri IV. Seminary in Paris, and after a brilliant course in the Polytechnic School in Paris, he entered the School of Mines in 1819, to devote himself to Mineralogy. Here he attracted the attention of the Professor of Geology, Brochant de Villiers, and together with his fellow-student Dufrenoy accompanied the Professor in 1822 to Great Britain, in order to become acquainted with the mines in that country and to get insight into the British methods of geological surveying. Élie de Beaumont and Dufrenoy then set to work in 1825 to prepare a geological map of France. At first they worked under the direction of Brochant de Villiers, afterwards they continued independently, and in eighteen years the map was completed. Its publication exerted a powerful influence on the whole development of geology in France, and secured for the two authors a distinguished place amongst their scientific contemporaries. In 1827, Élie de Beaumont was elected Professor of Geology in the School of Mines, and in 1835 he succeeded his patron, Brochant de Villiers, as General Inspector of Mines. He held in addition several high governmental offices, and used his influential position invariably for the good of his colleagues. After the conclusion of the general geological survey of France, Élie de Beaumont directed the special geological survey until his death on the 21st September 1874. The geological fame of Élie de Beaumont rests on his admirable field-work and his writings concerning the age and origin of mountain-systems. An account of his life and his contributions to science was published by Sainte-Claire Deville at Paris in 1878.

a short passage towards the close of this treatise. Brief although they are, the remarks on the influence of the slow cooling of the earth on surface conformation and the origin of furrows and fissures, are at once recognised by a reader of the present day as the starting-point of our modern views on mountain-structure. Favourable reviews by Brongniart and Arago helped to spread the fame of the young geologist, and to win rapid recognition for his work.

It was not until 1852 that Élie de Beaumont discussed the details in full, and gave expression to his conceptions in his three-volume work *On Mountain-systems.* He points out that in virtue of the continued cooling of our planet the radius is shortened and the crust is affected by a general centripetal movement. Delesse had calculated 1,340 metres as the amount by which the earth's radius had already been shortened; in other words, the earth's crust in the course of the geological epochs had approached the earth's centre by a distance about equal to the height of Chimborazo or the Himalayas above sea-level. As the more rigid crust tried to subside and accommodate itself to the contracting molten mass of the nucleus, inequalities and excrescences formed; or if the tension became too great a sudden rupture of the crust ensued, and the lateral compression gave origin to mountain-folding. The rock-masses in seeking relief from the crust-strains were pressed upward, and might under certain circumstances pierce the surface as a finger might pass through a button-hole. This, in Élie de Beaumont's opinion, was the explanation of the fact that granite masses so often form the summits and ridges of mountain-chains, whose flanks consist of uplifted sedimentary rocks. The latter, he said, were covered towards the base of the mountain for the most part by gently-inclined or horizontal strata, which spread over the neighbouring plains. The inclined strata often strike sharply against the horizontal layers, any marked contrast in the position of the neighbouring series of deposits indicating that *after* the deposition of the uplifted strata, and *before* the deposition of the undisturbed series, a convulsion of the earth's crust had taken place in that region and had culminated in the uplift of the mountain-chain. The exact geological period of the crust-paroxysm could be determined from a comparison of the ages of the inclined strata and the horizontal layers reposing upon them.

According to Élie de Beaumont, the ages of the mountain-systems as a rule correspond with the limits of geological formations, and therefore also with the "revolutions" indicated by Cuvier in the development of organic creation. The mountain-systems might in his opinion be regarded as chronological documents bearing witness to the paroxysmal stages in the physical history of the earth's crust. He then attempted to ascertain after this method the ages of the various mountain-systems in Europe, deriving his facts partly from his own observations, partly from literature.

While engaged on this inquiry, Élie de Beaumont became greatly impressed with the parallelism of the strike in the several component elements of a mountain-system. He remembered a saying of Werner's, that mineral veins with parallel strike afford evidence of the simultaneous origin of the vein fissures, and he applied this principle to mountain-systems, endeavouring to prove in the most detailed manner that mountain-systems or ranges with parallel strike were of simultaneous origin. The spherical form of the earth made it, however, difficult to determine the parallelism of mountain-systems far remote from one another, since in such cases the same term of geographical orientation would be used to describe directions which were not by any means parallel. Élie de Beaumont met this difficulty by treating the mountain-systems as tangents of earth-circles and arguing from the parallelism of the tangents. He regarded as parallel all mountain-systems which crossed the meridian at a like angle.

With the principle of parallelism, Élie de Beaumont left the sure ground of inductive reasoning and entered into speculative matter, which unfortunately he continued to discuss during the remainder of his life. In his description of the mountains of Europe, published in 1852, they are represented as tangents of twenty-one circles, and from the inclination of these circles to one another Élie de Beaumont deduced a general geometrical law of orientation for the mountains of the earth. He also constructed a "pentagonal net-work" of the fifteen largest circles which corresponded to the corners of a regular isogon in the centre of the earth, and made it the fundamental basis of his elaborate scheme of the earth's mountain-systems. But the famous "Réseau pentagonal" never received general recognition, although it was much discussed for a time by the personal adherents of Élie de Beaumont.

Several geologists, for example Studer and Hoffmann, who agreed with De Beaumont's fundamental ideas of upheaval by volcanic force, and his stratigraphical method of determining the age of mountain-systems, discredited his views regarding the simultaneous upheaval of parallel mountain-chains, as well as his assumption of sudden paroxysmal uplifts. They showed that the Alps, the Harz mountains, and the Erz mountains had suffered from repeated crust-movements. Still others, Constant Prévost, Ami Boué, Conybeare, and Charles Lyell, were in openly avowed opposition to Élie de Beaumont's doctrines from the first.

Professor Thurmann in Porrentruy made a series of valuable observations on mountain-making processes. This observer, who devoted his life to the study of the Swiss Jura mountains, elucidated their structure and composition with masterly skill and breadth of conception. The arched forms, so conspicuous a feature of the Jura Chain, were explained by Thurmann as crust-uplifts due to vertically-acting subterranean forces, and he quoted several examples to show how these forces may sometimes raise portions of the crust, and sometimes give origin to faults along which the uplifted chains are disjointed, and the several portions move apart.

Thurmann called the unbroken uplifted chains "arches," and distinguished as "combes" the crust-inthrows faulted into the middle of the arches; a "combe" wholly surrounded by faults was termed by Thurmann a "cirque." While he used the term "fold" for the crust-arches themselves, he applied that of "val" for the syncline or trough between neighbouring arches. He also gave distinctive names to mountain-valleys—the longitudinal deep ravines at the outer flanks of the chains he termed "ruzs," and the transverse valleys cutting through several chains "cluses."

The earlier treatises of Thurmann in 1830 and 1836 discuss the orographical features chiefly in relation to the original fold-forms of the Jura system and to general principles of mountain-folding and structures. His complete tectonical results regarding the causes and phenomena of relative crust-displacements were not published until 1856, a year after his death, at the age of fifty-one, from cholera. In these later papers Thurmann recognised the existence of one hundred and sixty incipient chains in the Jura mountains, only thirty of which could be regarded as of primary importance. He

said they were separated from one another by somewhat crooked fault-lines which ran in approximately parallel directions, or diverged at various angles of bifurcation from a main chain. In the case of the principal chains, the highest fault-blocks were those on the western side of fault-lines, and the mountain-curves were convex towards the west. Speaking generally, Thurmann distinguished in the Jura mountains a zone of the highest chains, a central zone of uplift, and a slightly-folded plateau zone. From the whole structure of the Jura, he finally concluded, in opposition to his earlier views, that the chains had not taken origin as vertical uplifts, but *that lateral forces had acted from the Swiss side and had compressed the strata along parallel folds.*

One of Thurmann's chief tenets was the long continuation of the plastic state in sedimentary deposits. He held that sediments remained plastic long after their deposition and during the processes of mountain-formation, and he therefore differentiated sharply between faulting, bending, crushing, and shearing movements effected while the sediments were still fairly plastic, and movements of adjustment accomplished after the mountains had been formed. He contested the hypothesis that rock already consolidated was reduced to a molten or plastic condition by the processes of mountain-making.

While Élie de Beaumont and Thurmann were building up their theories of mountain-upheaval upon field observations, the English physicist, Hopkins, was trying to solve the problem upon theoretical grounds, and one of his doctrines is specially worthy of note. From his consideration of the pressures exerted by explosive gases, vapours, and other subterranean forces upon the crust, he concluded that in almost all cases of crust-fracture two systems of faults must take origin at right angles to each other, and must then be fundamental directive lines during the formation of continents and mountain-systems.

Constant Prévost, in his report on the Island Julia (*ante*, p. 264), contested the theory of Elevation-Craters, and in opposition to Élie de Beaumont regarded the origin of mountain-systems and continents only as results of slow sagging of the crust, or of occasional inthrows when one side of the fissure was pressed outward and the rock-material was stemmed against it. Much later, similar ideas were enter-

tained by Professor Charles Lory, by Ebray and Magnan. Professor Favre also dissented from the supposed vertical uplift of the Alps. In 1867, in a now classic description of the geology of Mount Blanc, he ascribed the complex fan-shaped arrangement of the rocks in that mountain to the action of strong lateral pressure.

Important additions to the knowledge of mountain-structure were meantime being made by the North American Geological Survey. In 1842, at a Congress of British and American Scientists, H. D. Rogers had expressed his views on the stratigraphical composition, the tectonical relations, and the mode of origin of the Appalachian mountains. The one-sided asymmetric arrangement of the folds in the Alleghanies, the absence of any central axis consisting of crystalline eruptive rocks, the fact that the whole mountain-system was composed of numerous parallel folds, most of them curved in form, could not in Rogers's opinion be brought into harmony with the theories of mountain-upheaval which were at that time current in Europe. He argued against the conception that ascending eruptive masses uplifted superincumbent rock-strata, and also against Prévost's opinion that mountains were formed as a consequence of local inthrows and crust subsidences. His own theory of mountain-folding supposed the disturbing cause to be wave-like pulsations into which the molten magma of the nuclear body was thrown from time to time, when the accumulated tensions in the earth's thin crust caused an actual rupture. The form, arrangement, and inclination of the folded strata were ascribed to a combined wave-like and tangential movement, which was also accompanied by an injection of eruptive masses into the cavities created within the folds during the movement.

Professor Dana[1] was the geologist who first gave clear ex-

[1] James Dwight Dana, born on the 12th February 1813 at Utica in New York State, entered Yale University in 1833 and made a journey to Europe during his college course. In 1838 he was selected as geologist and mineralogist for the Wilkes Exploring Expedition, and during the four years' voyage became acquainted with the coasts of South America and the Pacific Ocean. Dana was shipwrecked off the coast of Oregon, but fortunately succeeded in reaching San Francisco and sailed once more by the Sandwich Isles, Singapore, and St. Helena to New York. Thirteen years were then devoted to the examination and description of his geological and zoological collections. His reports on the geology of the Pacific Ocean, the volcanoes of the Sandwich Islands and coral reefs,

SIR RODERICK MURCHISON.

From a Photo by Walker & Cockerell, London, E.C., of a Painting by S. Pearce.

pression to the theory of horizontal compression in explanation of the origin of mountains. The early papers by Dana upon crust-movements were published in the *American Journal of Science* in the years 1846 and 1847. In them Dana boldly contested the possibility of continents and mountains being raised by the expansive force of subterranean vapours and the ascent of rock-magma; and he also dissented from the gravitation theory of his compatriot, James Hall (1859), according to which the gradual accumulation of sedimentary masses in areas of subsidence must, on account of the altered equilibrium, give rise to folding and fracture of the crust, and consequently to mountain-chains. Hall's idea was to a great extent a modification of previous suggestions by Babbage and Herschel, but these investigators had attributed the subsequent uplift of thick deposits in areas of subsidence to the expansion of the sediments on account of the high temperature in their deeper horizons.

In common with Descartes, De la Beche, Cordier, Élie de Beaumont, and others, Dana considered the fundamental cause of crust-deformation to be the slow cooling and contraction of the earth's nucleus. But he made a closer geological investigation than any previous observer of the precise mode of action displayed by the contracting forces.

Dana assumed that the orographical limits of continents and mountain-chains were determined by certain pre-existing lines of minimum resistance (cleavage-lines) associated with inequalities of thickness and temperature in the earth's crust. He then argued that as the primitive earth cooled, the first crust-blocks that consolidated formed continents, and the pressure caused by shrinkage was most intense at the continental margins. There the greatest mountain-systems developed, and as a rule the height of a marginal mountain

as well as his comprehensive works on Zoophytes and Crustaceans, are amongst the finest productions in the literature of scientific travel. Dana was a Professor at Yale University from 1850 to 1894, and died on the 14th April 1895. He was distinguished as a zoologist, geologist, and mineralogist; his high merits were recognised in England by the award of the Wollaston and Copley medals. His *Text-book of Geology*, published in 1863, has since passed through several editions, and has had a marked influence on geological thought and progress. Over a hundred papers by Dana have appeared in the *American Journal of Science*, and they treat almost every subject of general geological interest.

range corresponded to the depth of a crust-hollow on the neighbouring portion of the ocean-floor.

This preliminary hypothesis is clearly open to question, but a more important feature is Dana's assumption that the centripetal movement of the crust, as it endeavours to shrink along with the nucleus, is transmuted into tangential tension comparable with the strains that would be set up in the case of a falling arch. In Dana's opinion the horizontal pressure components thus originated fold the crust into arched ridges and trough-like hollows. Dana called the latter *geo-synclinals*, the former *ge-anticlinals;* and he applied the qualifying term "monogenetic" to mountain-systems which owe their origin to a single arch or ge-anticlinal such as the Uinta mountains of Wyoming and Utah. On account of their frequent cracks and fissures, monogenetic crests are rapidly lowered by the action of subaerial denudation.

The mountain-systems composed of several chains always arise, according to Dana, within geo-synclinals where immense masses of sediment have collected. As the older rock-horizons become mantled by ever-increasing thicknesses of sediment above, and the subsidence continues, the deeper strata are weakened by heat and pressure and readily tear asunder. The broken fragments yield to the horizontal pressures, are crushed into a narrower space against the lines of tearing, are folded and thereby uplifted. Dana called a mountain-system elevated from a synclinal area of subsidence a "synclinorium." The deeper geo-synclinals of past geological epochs have been as a rule next the continents, and the new mountains originated there slowly, the movements occupying vast geological ages; after their emergence they were incorporated with the main continental masses.

Dana then discussed the conditions under which volcanic rocks might take a dominant part in the building up of mountain-chains. The earth's crust, he said, grew thicker by the continued progress of cooling, and the rocks became more and more resistant owing to the mechanical and chemical metamorphoses which they experienced in the crust. The process of mountain-making was consequently made more and more difficult in the older areas of disturbance, but as the tangential strain never relaxed, it might effect an upward pressure of the crust, culminating in rupture, and allowing the escape of volcanic rock at the surface. Hence the

youngest mountain-chains were pre-eminent for the large participation of volcanic rock in their composition, more especially along marginal fault-lines.

Dana's views on mountain-building were based chiefly on the Appalachian Rocky Mountains, and were well adapted to the geological relations in North America. They were therefore widely accepted in that country. Many of the ideas were criticised by his compatriots, and the healthy interest awakened in the subject reacted favourably upon Dana's concept, as it enabled the author to revise and improve certain portions. Joseph le Conte was the most brilliant of Dana's helpers in working out the evidences of horizontal components of pressure in mountain-folding; Dana so frequently cited Le Conte in his later publications that it is difficult to define the individual merits of the two geologists.

To the North American geologists undoubtedly belongs the credit of founding the theory of horizontally-acting forces and rock-folding upon an ample basis of observation.

Shaler distinguished between the uprise of continents and that of mountain-systems. Both were explicable upon the basis of the earth's contraction; but whereas the continents had taken origin from furrows which affected the whole thickness of the earth's crust, the mountains only represent foldings in the external parts of the crust which have served to relieve the lateral pressures produced by the contraction of the deeper horizons.

The method of research followed by Professor Suess marks the beginning of a new epoch in the questions of crust-deformation. Two aspects appealed strongly to Professor Suess, the tectonical problems presented by individual mountain-chains, and the relation of all the mountain-systems on the surface of the earth to the physical changes in progress since the beginning of the earth's history. Since Elie de Beaumont's misguided effort, no geologist had attacked the question from its universal aspect, and the supreme scientific success attained by the first volume of *Das Antlitz der Erde*, or *The Face of the Earth*, by Professor Suess, was a tribute to a work accomplished with the highest bibliographical skill and literary finish, the fullest geological and geographical knowledge, a convincing array of scientific facts that never fail to suggest an endless reserve in the background, and above all a calm, judicial, elevated tone of inquiry which the

end of the nineteenth century may well feel proud to have witnessed, and carried with it into its boasted wealth of scientific enlightenment.

His earlier geological papers on special areas show Professor Suess only as the ardent field-surveyor, the lover of mountains, the laborious student compiling results from his own note-books. But the little book entitled *Die Entstehung der Alpen*, or *The Origin of the Alps*, which was published in 1875, already betrayed the dawn of new thoughts, full of freshness and interest. Professor Suess in that work contested the upheaval of mountains and continents by forces acting vertically upward; he refuted the active participation of eruptive rocks in the origin of mountain-chains, and after a brilliant description of the most important mountain-systems of the earth, he demonstrated that any arrangement of those according to geometrical laws was altogether illusory. The difficult problems of crust-displacements were, he said, so intimately associated with the question of the age and origin of mountains that the latter could not possibly be solved by any mathematical deduction or general rule obtained from leading-lines of strike and distribution, but demanded an accurate knowledge of tectonical structure in each case.

A more detailed examination of the Alpine system[1] led Suess to the conclusion that the structure of this mountain-system was not symmetrical, as had previously been supposed, but was, on the contrary, essentially one-sided. The steep descent of the western Alps towards the plains of Piedmont and Lombardy indicated a curved fault-line, and the Alpine rocks had been folded together under the influence of a tangential force acting in north-west, north, and north-east directions from the leading crust-rupture. It had been customary to regard the zones of rock-formations on the south side of the eastern Alps as folded masses that had been pushed aside during the upheaval of the central chain, but Suess contested this, saying these zones represented an independent chain which had been pressed against the Alps by a horizontal force acting towards the north-west. He pointed out that farther east still another chain, the

[1] This name was applied by Suess in wider sense to include the Alps proper, the folded Jura mountains, the Carpathians, the Hungarian mountains, the Dinaric ranges along the eastern shores of the Adriatic Sea, and the Apennines.

Hungarian mountains, was introduced between the central Alps and the southern zones. Professor Suess then demonstrated a similar unilateral structure for the Balkan, Caucasus, and Ararat mountains, and in all cases the action of the tangential forces had been from south to north.

Hence a surprising similarity was demonstrated between the mountains of Europe and those in North America which had been described by Rogers and Dana, and the theory of lateral compression so widely accepted by American geologists seemed applicable to European mountain-chains with but few modifications. Élie de Beaumont's method of determining the ages of the mountain-chains was clearly unsuitable upon this new conception of their structure. According to Professor Suess, the tectonical disturbances which gave form to the present Alpine system had begun in the Mesozoic period, and had continued not only to the close of the Miocene time, but (at least on the southern slopes) into the Pliocene and possibly even the Diluvial Age. In considering the actual lines of deformation, Suess pointed out that allowance must be made for the retaining influences exerted by neighbouring immovable mountain-blocks, by ancient intruded and interbedded volcanic rocks, and by the resistance of the rock-folds themselves.

A study of the older mountain-masses (afterwards called "Horsts" by Suess) limiting the Alps on the west and north, showed that the same direction of force which had folded the Alps had also determined the structure of the Riesen mountains, the Sudeten mountains, the Bohemian forest, the Harz, the Ardennes, etc., and that this Central European mountain-system of high geological antiquity had, like the later Alpine system, been compressed by horizontal forces acting towards the north-west, north, or north-east. Although in Europe as in North America, the dominating direction of pressure had come from the south, there were also evidences of compression towards the south. Val Sugana in the southern Alps, Istria, Dalmatia and the Karst, the Ifer mountains, and the Teutoburg forest were mentioned as types of southward compression. Yet so prevalent was the northern direction of movement over vast regions between the Caspian Sea and the American shores of the Pacific Ocean, that one might feel tempted to deduce a general streaming of rock-material towards the North Pole throughout the whole Northern Hemisphere. But several facts contradicted such a con-

clusion. On the eastern boundary of the aforesaid region a number of disturbances were apparent, which were frequently associated with volcanic phenomena, and had caused the tremendous north-south fault of the Red Sea and the Jordan valley, also influencing the direction of strike of the Ural mountains and the western Ghats. East of this transversal line of disturbance, the leading Asiatic mountains had not in Europe the convex side of the strike-curves towards the north, but the convexities were towards the south.

A comparison of the Himalayas with the Alps showed a remarkable agreement between the two distant mountain-systems; Mesozoic, Palæozoic, and Crystalline rocks composed the high mountain-lands of both systems, yet there was the fundamental difference that the Tertiary rocks in the southern foreground of the Himalayas corresponded with those in the northern Molasse Zone of the Alps. Medlicott had already concluded from the general structure of the Himalayas that the chain had taken origin as the result of lateral compression from the north, and Suess tried to demonstrate a similar direction of movement, to the south or south-east, in other systems of Central Asia.

Suess agreed with Dana's opinion that the sedimentary rocks of the Euro-Asiatic systems had accumulated in pelagic geo-synclinals; and he brought the frequent gaps and unconformities in the succession of strata carefully into relation with former oscillations in the extent of the ocean. Suess described in greater detail the transgression of the Cenomanian Ocean which spread over a considerable part of Europe, North and South America, and northern Africa, and drew from it the conclusion that stratigraphical evidences of transgressions and withdrawals of the waters of the ocean were even more valuable as a means of determining the approximate eras of certain events in the Earth's history than the discovery of the relative ages of mountain-systems.

In the concluding chapter of this work on the origin of the Alps, Professor Suess summarised his results as follows:—the strikes of mountain-chains do not always run parallel with the greater circles of the earth, but may be diverted by various obstacles; the major fold-systems of mountains take origin frequently, if not exclusively, in geo-synclinals and demand enormous periods for their development. Volcanoes play a subordinate part in the formation of mountains. Most

mountain-systems have unilateral structure, and there has been in North America, Europe, and North Africa a general movement of rock-masses towards the north, in Asia towards the south.

Suess then enunciated certain principles of mountain-building. The simplest type of a mountain-system is that which begins with the occurrence of a rupture or fault rectangular to the direction of contraction, the severed crust-block then moving onward in the direction of the contraction (example, Erz mountains). The second and most frequent type is that which begins with the disposition of a principal fold striking transversely across the contraction and inclined in the direction of the contraction, a fissure then forming in the fold at the line of maximum tension. The front part of the fold moves in the direction of the contraction and pushes the sedimentary rocks before it into further foldings, the other part of the fold sinks, and volcanic rocks escape at the line of fragmentation and subsidence (example, Apennines and Carpathians). In a third type of mountain-building, several parallel folds arise, occupying a greater surface breadth, and usually ending on the inner side of the innermost fold with a steep crust-fracture (example, folded Jura mountains, Ardennes, Taunus, Appalachians). It depends on the intensity and direction of the folding-force, on the nature of the resistance, and on the greater or smaller brittleness of the varieties of rock, whether the secondary folds are preserved or if they are deformed and pass into faults whose planes are inclined inward to the mountains and serve as planes of overthrusting. In extensive regions the contracting force seems to have had the same direction during successive geological epochs.

Suess agreed with Shaler that the continents represent contractions of the whole earth's crust, whereas the mountain-systems are to be regarded merely as foldings of the more superficial layers of the crust. In addition to the folded mountainous portions of the earth's crust, Suess emphasised the presence of resisting crust-areas which, like Bohemia, are composed of old mountain-masses piled against or across one another like pack-ice, or like the vast Russian block consist of undisturbed horizontal strata. Such unyielding areas of the crust are frequently characterised by considerable gaps in the sedimentary series. Their geographical distribution decides the

form and the course of the folds into which the intervening more yielding portions of the earth's surface have been thrown by the tangential strains of contraction. While the first cause of mountain-making is the secular cooling of the crust, the precise form of a mountain-chain is subject to the modifying conditions introduced by these ancient and resistant crust-blocks or "archiboles."

The above are some of the leading conceptions in the remarkable work on mountain-structure published by Suess in 1875, and its great influence may be judged from the flood of literature upon this subject which has poured forth since that year. It is impossible to refer here to more than the most important of these publications.

After a long series of researches in a complicated district of Switzerland, Professor Heim, in Zürich, published in 1878 his famous work, *Untersuchungen über den Mechanismus der Gebirgsbildung.* The two geological maps and fifteen illustrative plates accompanying the text were lithographed by the author himself. The scientific insight and technical skill possessed by Professor Heim form a rare combination, and have brought his views on mountain-structure wide popularity and acceptance.

Heim concentrated his attention on the tectonical phenomena of folding. He depicted in the "Glarus Double-Fold" an appearance which seemed contradictory to any doctrine of mountain-movement, since on the north side of the central Alps, where, according either to the conception of symmetry or asymmetry of the chain the folds should have been towards the north, Heim's observations showed that the major folds on the north and south of the Glarus area had been overthrown towards one another, and the upper portions had continued to travel as "thrust-masses" advancing from opposite directions towards one another. This was clearly inexplicable on the assumption of a uniform direction of the horizontal movement of the crust, and Heim concluded that the inclination of overcast folds depended upon local inequalities of resistance, upon the presence of older folds as well as upon the relative height of the two bases of origin on the opposite sides of any individual fold. The second volume of Heim's work treats the general problem of Mountain Architecture. Using his own field observations as the ground-work of his discussion, he describes the phenomena of rock-deformation during crust-movement

under several headings:—curvature, plication, crush, shear, cleavage, distortion of rock-material and of fossils. He opposes Thurmann's idea that the rocks are primarily plastic and remain so during the mountain-movements, and assumes that the rocks of our mountain-chains have been first consolidated and afterwards altered during the crust-movements; the alteration might be accompanied by fissures and faults or might take place without any fracture, both modes of transformation being quite independent of the physical and chemical constitution of the rocks. Alteration without fracture only occurred at great depths, and was most frequent in the older rocks. According to Heim, the essential conditions for such alteration are the presence of a heavy superincumbent load of rock, and the action of pressures from all sides upon the rock-particles, so that even the most brittle mass of rock would be converted into a state of latent plasticity. The work done by horizontal pressures is the great truth which Professor Heim seeks to inculcate. He brings forward numerous observations to prove the passive behaviour of the "Central Massives" during the upheaval of the present Alpine system. In opposition to Studer's idea that the massives had represented active local centres of disturbance, Heim points out that the crystalline rocks present in these areas themselves show deformation and alteration explicable only upon the assumption that they had suffered no less than the rocks in the northern and southern zones of the Alps from a system of horizontal pressures common to the whole Alps. In Professor Heim's opinion, the individual forms of the Central Massives as lenticular or fan-shaped arches or simple domes had been determined by modifying local influences during the epochs of Alpine upheaval, but had no connection with volcanic subterranean forces. On the contrary there is, according to Heim, no field evidence whatsoever that the igneous rocks of the Central Massives exerted forces of compression upon the sedimentary strata in contact with them.

Heim therefore agrees with the general results of Suess, and explains mountain-making as a consequence of nuclear contraction, crust-subsidence, and the complex action of horizontal strains through the layers of the crust. He calculates that the plication of the Alps has reduced the breadth of that portion of the crust by a distance of about seventy-four miles; hence the crust contraction would seem

to be a very appreciable amount in the case of the greater mountain-systems. On the other hand, Heim calculates that the earth's diameter has not been shortened even one per cent. by the processes of subsidence and mountain-folding. With regard to the age of the Alps, Heim concludes that the central chains are older than the outer, that the strains have wholly ceased in the inner portions of the Alps, but continued along the northern chains into the youngest Tertiary periods, and are possibly even now in progress.

According to Heim's theory of latent plasticity, the rocks at a depth of nearly 7000 feet would be in a condition that would preclude the possibility of gaping fissures. This assumption is correlated with the characteristic feature in Heim's geological surveys, namely, the pre-eminence of folds in all possible forms, and the subordinate place assigned to faults. These have proved somewhat vulnerable points of attack in an otherwise classic work, and have been called in question by many eminent geologists during the twenty and more years that have elapsed since the publication of the *Mechanismus*.

Gümbel, Broegger, Stapff, Pfaff, Rothpletz, and others have opposed the theory of plasticity upon various grounds. All experimental attempts to reduce rocks by mere compression only caused fragmentation of the material. Pfaff found that many rocks might be subjected to a pressure of more than 20,000 atmospheres without showing any tendency to become plastic. Moreover, it is not in accordance with the known phenomena of volcanoes and earthquakes to assume that crust-fissures cease at comparatively small depths.

The experiments of M. Daubrée and M. Favre are especially noteworthy. Daubrée started from the standpoint that not only horizontal, but also vertical components of force have acted in bending and folding the rocks of the crust. His apparatus consisted of a rectangular iron frame, to contain the material under pressure. The pressure was applied from the side, but sometimes simultaneously from above. Instead of the alternating layers of wool, cotton, and clay which had been used in the experiments of Sir James Hall in Edinburgh, Daubrée arranged different kinds of metal plates and sheets of wax mixed with clay, resin, or turpentine. By varying the conditions of his experiments in respect of the intensity and direction of pressure, and the kinds of material, M. Daubrée

obtained types of folding and deformation which coincided with many of those represented in nature. The first account of Daubrée's results appeared in 1878, and in the same year Professor Favre of Geneva published his illustrations of clay strata which had been placed upon a stretched band of caoutchouc, and thrown into folds on the contraction of the elastic basis. In 1888, Mr. Cadell carried out a series of pressure experiments and attained excellent imitations of the tectonical disturbances in mountain-systems. An attractive experimental elucidation of the Appalachian mountains was given by Mr. Bailey Willis in his work entitled *The Mechanics of Appalachian Structure.*

All those experimentalists have demonstrated that under strong lateral pressure the material is not only plicated but is fissured and faulted in many different ways, and geologists generally are inclined to think that Professor Heim has not allowed sufficiently for the complicating effects of crust-dislocations.

The geological significance of fissures and faults was fully realised by the Wernerian School; this was only to be expected, since the foundation of Werner's doctrines was his intimate knowledge of the vein-rock that occurred in the crevices and fissures of the crust, and his careful observation of the relative displacements of the rock on the opposite sides of fault-fissures. From time to time special works on faults have appeared in mining literature. One of the best known earlier works is Carnall's description of the fissures in the Carboniferous district of Silesia, published in 1836; numerous special papers on the British mining districts are included in the Reports of the Geological Survey; and Köhler in 1886 published a valuable monograph, entitled *Die Störungen der Gänge, Flötze und Lager.*

The faults in mountain-regions were examined by De la Beche, Sedgwick, Thurmann, Harkness, and many others, and their origin commonly ascribed to contraction and mechanical strain; William King explained them as due to processes of crystallisation. The mechanical strains in the crust during mountain-making are undoubtedly the most important factor, and Professor Daubrée imitated the effects of strain in a series of experiments. He subjected plates of glass, pieces of rock, and wax prisms to torsion and to vertical and lateral pressures, and produced fissures and displacements which could bear

detailed comparison with the phenomena of crust-fracture in nature. Daubrée also elucidated the influence of such fractures on the subsequent surface conformation of the earth, and especially on valley erosion.

Reyer in his *Theoretische Geologie*, published in 1888, discusses the causes and phenomena of crust-ruptures. He refers fractures to differences of tension arising from various causes, inequality of the superincumbent weight or in the rate of gain and loss by chemical changes, and inequality in the access or abstraction of heat in the rocks of adjacent areas. Dr. Reyer cites numerous examples of step-faults, trough-faults, and fault-nets, in order to show that areas of subsidence bounded by fault-fissures are frequently strengthened by the injection of eruptive masses, and are rendered so much the more resistant in subsequent crust-disturbances.

The first volume of Suess's *Antlitz der Erde* appeared in parts during the years 1883-85; the second volume followed in 1888; and the third and last volume has recently been completed. The author incorporates in this work many ideas which he had enunciated in skeleton in the *Entstehung der Alpen*. But the later work is not limited to the consideration of the origin of mountains and continents, it surveys the whole history of terrestrial change in the course of the geological epochs. In the hands of the most accomplished of foreign geologists, and one of the strictest logicians of any age, crust-tectonics may be almost said to have been elevated into a new inductive philosophy of earth-configuration.

The leading purpose of the work is to explain the present conformation of the earth's surface upon the basis of the previous changes in the oceans and continents of the earth. And first the movements in the solid outer framework of the earth are considered.

Suess begins by discussing the Deluge of the Scriptures, as one of the last grand geological events, which visited Mesopotamia with a devastating inundation, probably the result of an earthquake or a cyclone from the Persian Sea. In addition to the Mosaic account, the Izdubar Epic of the Babylonian Berosus serves as the historical basis of this chapter.

A second chapter treats of Earthquakes, and a third elucidates the various kinds of dislocations associated with the *contraction* of the earth's nucleus. The movements are

resolved into tangential and radial tensions, which give effect to horizontal and vertical displacements. Under horizontal displacements Suess describes folds, anticlinal domes, overthrusts, and lateral shifts effected by dip-faults. The vertical displacements are evidenced by subsidence or inthrows, and they are accompanied by numerous fissures and faults, which may again be sub-divided into peripheral, radial, diagonal, and transversal faults. The nature of the subsidence in dislocated segments of the earth's crust determines the arrangement of the faults as limiting-lines of crust-basins, crust-troughs, flexures, or table-lands. The combination of a subsiding and tangential movement gives origin to specially complicated tectonical appearances, such as the development of fore-folds and back-folds.

Suess regards volcanoes only as slight and superficial indications of important phenomena in the nuclear mass of the earth. He describes a number of examples showing the gradual denudation and partial disturbance of volcanoes, and establishes a "series of denudation forms" intended to prove that there is no fundamental difference between the volcanic explosions and ejections of the present time, the massive flows of earlier periods, and the laccolites and deep intrusions of the oldest periods. The fissures and dykes of active and extinct volcanoes are carefully discussed, also the dislocations caused by earthquakes.

After these preliminary chapters, Suess makes a comparative investigation of the mountain-systems of the earth, and an attempt to discover their geological history from their tectonical structure. To the geologist the subject is opened out with unflagging interest. Beginning with the Northern Sub-Alpine area, Suess emphasises the obstructive influence which had been exerted by the mountain-ranges of Central Europe, the Sudeten mountains, and the Russian plateau. These resisting crust-blocks had for the most part successfully stemmed back the advancing Alpine folds, or in the case of the Sudeten and a part of the Russian plateau, the northward crust-creep had carried the Carpathian folds partially over the ancient mountain-masses.

Suess elucidates the direction of strike of the dominant folds in the Alpine system, and his description of the curvature and whirl-shaped arrangement of the leading lines of strike has thrown an entirely new light upon Alpine geology.

The older view, that in the Northern Hemisphere, from the Caspian Sea to the American shores of the Pacific, folding-movements had been directed to the north, north-west, or north-east, is shown to be erroneous for the southern Apennines and other outrunners of the Alpine system, as well as for the coastal chains in North America. A special chapter is devoted to the work of Mojsisovics on the inthrown area of the "Dolomites" in South Tyrol, with which the origin of the Adriatic Sea is associated.

Another chapter is devoted to the geological history of the Mediterranean Sea, which he proves to be a remnant from a much greater ocean. He calls this ancient ocean "Thetys," and by an exhaustive discussion of the various Tertiary deposits demonstrates the former extent, boundaries, and phases of development of the original ocean of "Thetys." It extended across the Atlantic Ocean to the southern coasts of North America, and through Central Europe to the inner recesses of Central Asia. The fragmentation of the neighbouring continents, the recent inthrows of the Ægean and Black Seas, are described with admirable mastery of detail.

The following chapters treat the Sahara table-land, with its continuation towards Arabia and Palestine; the broad South African table-land, which formerly extended as "Gondwana Land" across Madagascar to Southern India and Australia and is bounded on all sides by a faulted coast; and lastly, the mountain-systems of India and Central Asia and their tectonical relations to the Alps and European mountains. Suess then proceeds to describe the leading features of America. In South America there is a certain unity of structure. In the east and in the middle the great Brazilian table-land is composed of little disturbed Palæozoic strata; in the west the folded mountain-chains are mostly composed of Jurassic rocks. Still younger strata occur near the Pacific coast, and the volcanoes and earthquakes of this area indicate the continuance of crust-disturbances in the present day.

Central America is interposed between North and South America with a structure geologically independent of either, and representing a part of the former land-girdle of the Thetys. In North America, the Appalachians, the Mountains of the West, and the intervening table-lands afford the author frequent opportunity of discussing the American literature on the origin of mountain-systems.

The first volume concludes with a summary of the most important results obtained throughout the work. It is pointed out that the names Old and New World are, geologically speaking, quite unjustified, as the greater part of North America has been exposed as dry land since the Cretaceous epoch, and is therefore of considerable antiquity. South America has its own distinct structure; it may be described as a gigantic crust-buckle bounded on three sides by high mountain-walls, but unbroken by any tectonical lines towards the east and north-east.

In the Old World three dissimilar regions have been welded together: (1) the southern parts of the ancient Gondwana Land, which has never been completely submerged since the conclusion of the Carboniferous epoch; (2) Indo-Africa, the present Sahara, Egypt, Syria, and Arabia, covered by the ocean in the Cretaceous epoch, but never subjected to folding-movements since Palæozoic time; and (3) Eurasia, the north-west of Africa, Europe, and the remainder of Asia. The southern borders of Eurasia are strongly folded, and throughout long tracts they have been thrust above the Indo-African table-land.

The second volume begins with a historical account of the different opinions regarding secular movements of upheaval and depression of the land. Suess points out the advantages of the terms "positive" and "negative" as signifying the relative character of coastal displacements (*ante*, p. 292).

Two of the most brilliant chapters in the work are devoted to the boundaries of the Atlantic and Pacific Oceans. All the erudition of a century is summed up in these pages; as one reads, broad geological portraits of the face of the earth as it is and as it was are called forth, till one forgets to marvel at the magician's touch or question the individual features. A comparison of the North European and North American fault-areas discloses unexpected homologies between the two territories. The re-construction of the ancient Armorican and Variscan mountain-systems in Central Europe, the elucidation of their losses by fracture and denudation, and the proof of the similarity in the direction of the later folding that gave origin to the Alps and Pyrenees, are masterpieces of scientific argument.

The *Face of the Earth* is intended, however, not only to explain the origin of mountains, but also to trace in chronological succession the chief vicissitudes of the solid crust since

it began to form. A detailed account of the Palæozoic, Mesozoic, and Tertiary oceans, with their transgressions and retrogressions, comprises many new conceptions, and leads the author finally to the consideration of the oscillations of the ocean surface at the present day. The emerging coasts of Scandinavia are viewed as proof of lowered sea-level, and the general opinion in favour of crust-elevation is strongly opposed. Similarly, Suess explains the strand displacements in progress on the coasts of the Mediterranean Sea, the Pacific and Indian Oceans, as the result of movements in the aqueous envelope of the earth, but not in the solid crust.

According to Suess, ruptures and collapses affecting the whole thickness of the earth's crust, together with tangential folding of the upper horizons, are the forces to which the earth originally owed its surface conformation. There is no such thing as an active or passive emergence of portions of the earth's crust; in the estimation of Suess, the theory of elevation is a great error. He thinks it impracticable to ascertain the ages of the mountain-systems by any such ingenious method of calculation as Élie de Beaumont attempted, seeing that as a rule the upheaval of a mountain-system occupied protracted intervals of time. Nevertheless, Suess is inclined to correlate the grand physical events of the earth's history with those of the development of the organic world, and thinks it possible in this way to erect a natural and universal classification of the formations. For this purpose it is not so much the origin of new mountain-systems that comes into question as the periodic recurrence of those great pelagic transgressions, whose cause of origin until now has not yet been discovered.

Many of the hypotheses suggested by Suess will probably not endure the criticism of the future. Yet there can be no doubt that even the expression of a hypothesis having due respect to all known data marks an important step in advance. In the midst of the present activity in conducting detailed investigations there is a certain danger that scientific workers may become parochial in their interests and teaching; but a work like that of Suess, so cosmopolitan in its standpoint, reminds all workers of their community of aim, rouses each one from the particular to the general, and brings him back with renewed vigour and mental insight to the particular. The time was ripe for an effort to establish systematic clearness in the acquired abundance of detail and to seek for compre-

hensive laws and principles. One of the most distinguished of living geologists, Professor Marcel Bertrand, writes in the preface to the French translation of Suess's work, by M. de Margerie: "The creation of a science, like that of a world, demands more than a single day; but when our successors write the history of our science, I am convinced that they will say that the work of Suess marks the end of the first day, *when there was light.*"

Suess has secured almost general recognition for the Contraction Theory. Yet there are individual attempts to explain mountain-making in some other way. Amongst these the most worthy of note is Mellard Reade's attempt to work out the Huttonian expansion theory in detail and to make it agree with the ascertained facts of modern geology. Mellard Reade made a number of experiments on the expansion of metals and rocks under different modes of heating, and applied his results theoretically to explain the movements within the earth's crust.

Like James Hall and Dana, Mellard Reade starts with the assumption that mountain-making takes place only in districts of thick sedimentary deposits, and that there is an increase of temperature in those parts of the earth's crust on account of the additional thickness, and therefore proportional with it. Whereas Babbage, Lyell, Dana, and others suppose that the force of expansion called forth by the increase of temperature acts only in linear directions, vertically upward, Mellard Reade shows that this force must tend to expand rocks cubically, *i.e.*, upward, downward, and laterally. The lateral expansion of the rocks in the heated area is resisted by the relatively less heated rocks of adjacent areas, the compression of the expanding rocks causing them to fold and buckle. The upper layers being less influenced by the earth's heat than the lower are in a condition of greater tension, while the lower are more strongly compressed. Both are separated by a neutral zone, in which the rocks experience neither tension nor compression; this zone is called the "level of no strain."

The rocky floor upon which the thick mantle of deposit has gathered necessarily participates in the subsequent rise of crust-temperature, the expansion, and the compression. Therefore the sedimentary strata of high antiquity composing the floor are subjected anew to heat and pressure, are folded and crushed in the most varied manner; and in their plastic state, since they are stemmed back by the lateral resistance of cooler areas and harder masses of rock, they are readily pressed

towards the lines of least resistance in the mountain-system, namely, the anticlinal axes of the folds and arches. Thus they accentuate the appearance of upheaval at the surface, and form the axes of the highest chains, which as a rule consist of ancient crystalline rocks.

But as the origin of a mountain-system occupies long geological epochs, many changes of temperature may take place in the subterranean masses. Every rise of temperature causes a new movement of expansion, and the mountain-chains may rise higher and higher above the surrounding areas. Fissures and faults are phenomena of contraction produced by cooling, and are therefore usually younger than the folding and upheaval of the mountain-chains. With every crust-rupture a subsidence of one or both sides of the fissure is commonly associated.

Mellard Reade cites examples chiefly from British and North American geological literature in support of his theory. The weakness of the theory consists in its treatment of mountain-making as a merely local phenomenon; it assumes rather than explains that the expansion of limited crust-blocks by little and little can effect the uprise of vast mountainous tracts.

The American geologist, C. E. Dutton, in a paper "On some of the Greater Problems of Physical Geology," in 1892 also contests the Contraction Theory and proposes his theory of "Isostasy." He points out that the earth's crust is not homogeneous, but consists of heavier and lighter masses; the effort to arrive at equilibrium causes the heavier masses to subside and the lighter masses to rise as crust-buckles. If an area which has already subsided is weighted by thick masses of sediment it must sink farther, and if simultaneously the adjacent crust-buckle is lowered by the agencies of surface denudation, the socket of the arch is so much lightened and rises farther. Should these movements overcome the rigidity of the earth's crust, Dutton supposes that in the littoral sediments, crust-creep or flow takes place towards the continent in course of denudation, and this flow movement may become so intense as to produce folds and build up mountain-chains.

Dr. Reyer, another opponent of the Contraction Theory, has suggested a theory of mountain-making based upon extensive crust-slip. He assumes that every system of crust-folds begins with a crust-rupture and with the sinking of several crust-blocks towards one direction, so that the earth's relief is made unsymmetrical, with a definite slope on one side. If

the sedimentary rocks beside a rupture are tilted by upheaval, then, according to Reyer, the rock-strata glide downward and as they do so fall into complicated folds.

An Alpine geologist of wide experience, Professor Rothpletz in Munich, holds the Contraction Theory to be inadequate as an explanation of volcanoes and of the unlike distribution of gravity in the earth's crust. He believes that a better explanation is afforded on the basis of crust-expansion in certain regions.

Rothpletz recognises three distinct spherical zones of rock-material in the earth, according to their physical condition. Below the rigid crust is the viscous or molten nucleus, and between both a zone of cooling and consolidation. Professor Rothpletz assumes that the masses in the intermediate zone do not contract as they would on cooling under normal pressure of superincumbent rock, but expand as they cool, in analogy with bismuth and other substances. From this zone, therefore, vertical and tangential pressures are exerted upon the solid crust. At localities of weak resistance the crust is torn, the expansion of the intermediate zone pushes the crust upward and produces continents or table-lands at the surface, and the seams are invaded by the uprush of molten magma from the nucleus. At the same time the tangential tension in the emerged continents tries to relieve itself locally by the formation of folds. Hence mountains are upheaved and volcanic invasions occur on the continents at the places of least resistance.

CHAPTER IV.

PETROGRAPHY.

THE investigation of the rocks which compose our earth's crust has always been conducted along two directions of study: (1) the investigation of the mineralogical and chemical composition, the structure of rocks, their mode of occurrence; (2) the investigation of their mode of origin.

The systematic arrangement and the morphology of rock-varieties has been constructed mainly upon a mineralogical basis; the questions concerning the origin of rock-varieties have been handled more from the geological and chemical side. A distinction between massive eruptive rocks and stratified deposits was early recognised in petrographical literature. Hutton's was the genius which first differentiated clearly between plutonic, volcanic, and sedimentary rocks in point of origin; while Werner, too biassed by Neptunistic doctrines to perceive the fundamental truths which Hutton had taught, nevertheless accomplished the task of erecting a systematic classification of rocks upon mineralogical considerations.

During the first half of the nineteenth century, all petrographical works followed Werner's system. His determination of rocks as simple or composite occurs in most of the later attempts at classification, and also his fundamental principle of differentiating the essential and the accessory minerals in mixed rocks has been continued to the present day.

Brongniart had in 1813, in his table of Composite Rocks, assigned great importance to the structural relations, and distinguished accordingly three chief classes: 1, the "isomerites," or granitoid varieties of rock, in which the individual elements are united only by crystalline aggregation, and there is no finer matrix, *e.g.*, granite, syenite, protogine; 2, the "anisomerites," or porphyritic and hemicrystalline varieties,

in which the chief mineral constituents lie imbedded in a "matrix" or ground-mass, *e.g.*, gneiss, schist, phyllite, porphyry, trachyte, obsidian, lava; 3, the "aggregated" or fragmental varieties, which take origin by mechanical means, and whose ingredients are cemented together by subsequent infilling of material, *e.g.*, psammites (sandstone, greywacke), pudding-stones, and breccias.

Brongniart, as well as his predecessors Hauy and Cordier, confined themselves exclusively to the mineralogical composition and structure of the rocks, without respect to their mode of occurrence, their age, or their origin. While this method of treatment proved undoubtedly beneficial to the development of systematic petrography, it endangered the connection between geology and petrography, and in this respect the direction initiated by the French petrographers must be regarded as retrograde in comparison with the Wernerian School.

The best and most complete work of that time on petrology was Leonhard's[1] *Charakteristik der Felsarten* (1823-24). In this work likewise the mineralogical standpoint predominates, but the Wernerian influence is apparent in the frequent digressions which give information regarding the occurrence of the different kinds of rock in the field and their mode of origin. Leonhard distinguished four sub-divisions of rocks: 1, rocks composed of unlike elements; 2, rocks apparently uniform; 3, derivative or fragmental rocks; 4, friable and incoherent rocks. As all Leonhard's distinctions were founded on macroscopic examination of the rocks, the group of the "apparently uniform" rocks is quite artificial, and the limits of the others are unsatisfactory.

Cordier[2] had suggested in 1815, according to the precedent

[1] Carl Cäsar von Leonhard, born 1779 at Rumpenheim near Hanau, studied in Marburg and Göttingen; in 1800 entered into the Hessian Government Service; in 1810 was appointed Councillor of the Exchequer in Chur Hesse, and afterwards Director of Domains; in 1816 accepted a call to the Munich Academy, but left Munich in 1818 to be Professor of Mineralogy and Geognosy at the University of Heidelberg, where he died on the 23rd January 1862.

[2] Pierre Louis Antoine Cordier, born 1777 in Abbeville, began life as a mining engineer in 1797; took part under Dolomieu in the Egyptian Expedition; in 1819, succeeded Faujas de Saint-Fond as Professor of Geology at the Botanical Garden, and at the Restoration of the Empire was made a peer of France. He died in 1862.

of Fleuriau de Bellevue and Dolomieu, to pulverise the apparently homogeneous rock-varieties, to separate the particles by weight, and test them partly below the microscope, partly with the magnet, partly by chemical means; but this manner of research proved far from successful, as it was extremely difficult to identify the minute mineral particles. It showed, however, that basalt was a composite rock.

The Scottish geologist, Professor William Nicol, in 1827 introduced a method of preparing thin sections of fossil woods to be examined by the microscope, and about the same time constructed a polarising microscope for the special investigation of crystals. The insight of this gifted man in petrographical pursuits, no less than in respect of the difficult problems of the geology of the Scottish Highlands, failed to carry conviction into the minds of his contemporaries. A few petrographers certainly adopted his method of examining fossil woods, and it was by this means that Göppert was enabled to detect the important constituents of coal.

In the hands of Ehrenberg, the microscope proved of epoch-making significance. By its use Ehrenberg made the discovery that a number of widely distributed rocks, soft in character, such as chalk and tripolite, as well as certain limestones from the older formations, were entirely composed of the skeletons of lowly organisms (diatoms, foraminifera). Ehrenberg's work on chalk and chalk-marls was published at Berlin in 1839; fifteen years later, in his *Mikrogeologie*, he gave a complete account of his microscopic investigations on the composition of sedimentary deposits, the work being enriched by a very large number of excellent illustrations.

Although Ehrenberg's method of microscopic examination of friable and earthy rock-material had been so eminently successful, it did not seem as if it could be adapted for the investigation of the harder rocks. The thin splinters of a crystalline rock were not sufficiently transparent even when imbedded in Canada balsam, and Nicol's optical method of identifying the mineral fragments was little known. Besides Nicol himself, David Brewster and Humphrey Davy interested themselves in the microscopical examination of the structural relations of minerals, and the frequent fluid inclusions of rock minerals. Scheerer in 1845 identified the hemicrystalline structure of many apparently homogeneous rocks, and in transparent chips of crystals examined by transmitted light

he recognised numerous minute foreign bodies and inclusions. But these authors failed to make sufficient impression upon contemporary thought. Petrography continued to be conducted for the most part along the old lines; in Germany the best known teachers of petrography were Rose, Cotta, Naumann, and Rath; in France, Delesse, Durocher, and Fournet. Naumann's *Lehrbuch* contains an admirable representation of the state of petrography in 1850. But, instead of the subdivisions then customary, Naumann differentiated rocks chiefly according to their origin as crystalline, clastic, hyaline, poriform, zoogene, and phytogene.

In the following decade, the interest of petrographers was chiefly directed to the chemical side. Until that time, geology had troubled little about chemistry. The foundations of geology had been laid without the assistance of chemistry; among the leading geologists of the heroic period, only Hutton and De Saussure were learned in chemistry, and they had not seemed to find much use for their intimate knowledge of that branch of science. Cordier had in 1815 applied hydrochloric acid for the determination of certain constituents of rocks, and Gmelin in 1828 had made an analysis of phonolite, separating the elements that were soluble in hydrochloric acid from those that were insoluble. But a purposeful chemical investigation of rocks was first attempted by Bischof and Bunsen.

Gustav Bischof (*ante*, p. 217), the founder of Chemical Geology, was much more a chemist than a geologist, and although his lack of sound geological knowledge could not affect his experimental chemical researches on rocks, it proved detrimental when he came to draw generalisations from his results. In the first volume of his *Text-book of Chemical and Physical Geology*, Bischof begins with the consideration of the water on the surface of the earth and in internal cavities and joints; after a detailed description of springs, he turns his attention to their temperature, their chemical ingredients, etc., and to the chemical changes which are set up in the rocks when water is brought into contact with them. The second volume is a complete chemical mineralogy and petrology, in which the mode of origin of the rocks receives a large share of attention. When he reviews his facts, Bischof arrives at conclusions of an ultra-Neptunistic tendency and quite erroneous. The work is of high value on account of the

large number of careful rock analyses, which show the relative admixture of the different rock-forming substances. By careful chemical analyses, Robert Bunsen succeeded in distinguishing between two volcanic magmas exuded from different vents in Iceland—the one, a normal trachytic or acid magma, the other a normal pyroxenic or basic magma,—and showed that from the combination of these all possible transitional varieties of eruptive rock might take origin. After the publication of Bunsen's paper in Poggendorff's *Annalen* in 1851, geologists were so zealous in the chemical investigation of rocks, that almost a thousand chemical and mechanical analyses of rocks were forthcoming ten years later when Justus Roth prepared his tabular list of rock analyses.

In the year 1850, Henry Clifton Sorby published a short communication on the Jurassic Calcareous grit, whose structure he elucidated by applying Nicol's methods of examining thin rock-slices by transmitted light. In two further treatises in 1853 and 1856 Sorby tried to solve the problem of cleavage by similar means of examining thin sections of cleaved rock. These earlier writings of Mr. Sorby were the precursors of his famous memoir in 1860, which revolutionised the teaching of petrography. Independently of Sorby, Oschatz in Berlin had recognised the importance of preparing thin slices of rock for microscopic examination. On the 7th January 1852, Oschatz exhibited a collection of fifty microscopic slides of mineral sections at a meeting of the German Geological Society, and again in 1854 at a Scientific Congress in Göttingen, but he did not succeed in arousing any great interest.

The turning-point was Sorby's classic paper on the microscopical structure of crystals, published in the *Quarterly Journal of the Geological Society* in 1858. This paper demonstrated the structure of rock-forming minerals with unprecedented accuracy; it compared the natural mineral crystals with crystals artificially produced, and finally drew definite conclusions regarding the origin of the different rocks. Sorby was able to deduce from the presence of fluid, gaseous, crystalline, vitreous, and slaggy inclusions in crystals, the aqueous or volcanic origin of certain rocks, and thus brought to an end questions which had been for many years matters of dispute, and which could never have been solved without a precise knowledge of the mineralogical elements and ground-

mass of rocks. Sorby's paper was no less than epochal in its effect, it appealed both to field geologists and to mineralogists, for it revealed the community of interest in the results which could be obtained by accurate microscopic examination of rocks.

Sorby's method was applied by Websky, who examined thin sections of minerals by polarised light, and attained brilliant results. A happy circumstance brought Sorby's influence directly to bear upon Ferdinand Zirkel. In the year 1862, while at Bonn, Sorby personally initiated Zirkel into his methods of investigation, and inspired him with enthusiasm for the new field of research.

Specimens of crystalline rocks from all parts of the world were secured by Zirkel, who submitted them to microscopic examination by transmitted and polarised light, and arrived at ever sharper definitions of the various inclusions, and the appearances displayed in polarised light. By his comprehensive researches Zirkel established Sorby's methods upon a broader empirical basis, and he at the same time introduced the new methods in his teaching of petrography at Bonn University.

There were still some incredulous voices: Vogelsang in 1864 doubted the existence of glassy inclusions in the component ingredients of porphyry, and other rocks of non-glassy structure; Laspeyres in the same year also disputed the glassy inclusions in porphyritic rocks of Halle, and even doubted the distinction between glass and water vesicles.

The publication of Zirkel's *Lehrbuch der Petrographie* (Bonn, 1866) may be said to mark the culmination of the older methods, and the academical initiation of the new. In his text-book Zirkel embraced all that was known about the mineralogical and chemical composition, the structure, systematic arrangement, the mode of occurrence and origin of the various rocks; he also described the crystallographical results which had already accrued from microscopic investigation, and indicated the far-reaching advantages opened up by the new direction of research. Zirkel's work removed all doubt regarding the value of the microscopic results for systematic petrography.

Vogelsang, in his *Philosophie der Geologie und Mikroskopische Gesteins-Studien* (Bonn, 1867), accepted the new teaching in full, and added much to the knowledge of the

porphyritic series by his careful microscopic investigation of the larger mineral constituents and the ground-mass characteristic of different varieties. Vogelsang's observations on the processes of the consolidation of rock-magma, on the microscopical structure of slags, on "fluidal" structure, on microlites, and on conditions of devitrification, are clear and accurate. His illustrations are throughout of high excellence; and his proof, given in collaboration with Geissler, that certain liquid inclusions in minerals and rocks consist of liquid carbonic acid, is a discovery that will ever remain associated with the name of this promising scientist, who unfortunately died before he reached his prime.

Special memoirs were contributed by Zirkel on phonolite, on glassy and partially glassy rocks, and on leucite rocks. A very important work was his *Untersuchung über die mikroskopische Zusammensetzung und Struktur der Basaltgesteine* (Bonn, 1870). In this work, Zirkel showed for the first time that the basalts and the lavas corresponding to them may be classified in three groups (felspar, nepheline, and leucite basalts), and that each of these three modifications can be identified by its constitution and structure, as well as by the ground-mass.

A few months before the appearance of Zirkel's work on basalt, Tschermak had published a short but valuable paper on the microscopic differentiation of the minerals belonging to the augite, hornblende, and biotite group, and thus removed one of the chief difficulties in the identification of rock-forming minerals.

The year 1873 was signalised by the almost simultaneous appearance of two works, in which the two most distinguished masters in the domain of microscopical research comprised the quintessence of their investigations. Under the title, *Die mikroskopische Beschaffenheit der Mineralien und Felsarten* (Leipzig, 1873), Zirkel gives an introductory code of instructions as to the use of the microscope, examination by means of polarised light, and the methods of producing faithful illustrations. He then describes the microscopical structure of rock-forming minerals with special respect to the various kinds of inclusions and the products of decomposition. The optical and physical characteristics of mineral sections are next described; and the results obtained in the earlier chapters on minerals are applied in the latter half of the work,

which is devoted to the mineral constitution and structural features of rock-varieties. The work is fully illustrated by woodcuts.

The other important work was that of Rosenbusch, entitled, *Die mikroskopische Physiographie der petrographisch wichtigen Mineralien* (Stuttgart, 1873). It contains an exhaustive statement of the practical methods according to which rocks may be identified by means of the morphological, physical, and chemical properties of their component minerals; this is followed by a full and methodical discussion of the microscopic characters of rock-forming minerals. The optical consideration of the phenomena of polarisation was elucidated so admirably by Rosenbusch, that his work created a secure basis for future petrographical researches. By the improvement of the microscope and the polarising apparatus, by the introduction of a rotating stage, and by other mechanical aids, it was now rendered possible to distinguish not only singly or doubly refracting bodies and uniaxial or biaxial minerals, but also to determine more accurately the specific optical properties of minerals belonging to the different systems of crystallisation. After the publication of this great work, Rosenbusch took rank along with Zirkel as one of the great pioneers in the microscopical investigation of rocks. In 1877, Rosenbusch published a second volume entitled *Die mikroskopische Physiographie der massigen Gesteine.*

Rosenbusch distinguished the massive rocks according to the felspathic modifications:—1, Orthoclase rocks; 2, Orthoclase, nepheline, leucite rocks; 3, Plagioclase rocks; 4, Plagioclase, nepheline, leucite rocks; 5, Nepheline rocks; 6, Leucite rocks; 7, Non-felspathic rocks or peridotites. Each of these groups was subject to further sub-division according to the particular rock-structure, or in the case of the felspathic rocks according to the presence or absence of quartz. Like Zirkel, Rosenbusch gave due consideration to the geological age of the rocks, as the older and the younger representatives of each group were handled separately.

The optical method brought to such a high point by Rosenbusch was still further elaborated by Bertrand, Klein, and Lasaulx in memoirs which appeared in 1878. Schuster proved in the following year that the felspars which had been recognised in such a masterly way by Tschermak from their composition to be isomorphous mixtures, represented a

series of closely-related modifications which could be optically distinguished.

In addition to the service rendered by microscopic methods in facilitating the accurate mineralogical identification of the chief constituents of rocks, these methods disclosed the existence of a considerable number of subordinate mineral constituents which had either been wholly overlooked by macroscopic research or had been supposed to be extremely rare.

To mention one example, augite was found to be present in granite, porphyry, rhyolite, phonolite, etc. This discovery was a direct contradiction to previous teaching that certain minerals could not exist in association with each other in the same rock; amongst other couples quartz and augite, orthoclase and augite, leucite and plagioclase, had been said to be mutually exclusive.

Microscopical research made it possible for the first time to attain a clear conception of the different kinds of rock-structure. The composition and structure of the ground-mass in hemicrystalline rocks was revealed, and new light was thrown upon characteristic structures of glassy rocks, fluxion structure, spherulitic and perlitic structure. Hence with the aid of the microscope the origin of the crystalline rocks began to be better understood, and their relations to the group of apparently homogeneous rocks.

The indifference with which the large body of geologists had long viewed the microscopic study of rocks now gave place to zealous interest, and from the year 1870 the very large number of special papers that were devoted to petrological subjects not only filled Mineralogical Journals, but occupied a large share of the space in the Journals of Geological Societies. The sudden influx of new literature was unprecedented, and it would be hopeless to attempt to mention individual papers in the present work. Between 1870 and 1880, two-thirds of the publications on microscopic petrography belonged to Germany and Austria. Amongst British workers Allport, Rutley, Houghton, Bonney, Archibald Geikie, Teall, Harker, may be named; in North America some of the pioneers were A. Hague, Whitman Cross, Iddings, G. H. Williams, Wadsworth, Lawson.

The results of these researches necessitated many changes in the systematic arrangement of the rocks, and in no group was

the influence of microscopic study more revolutionary than in that of the massive rocks. Zirkel, in 1866, classified the massive crystalline rocks mainly upon the basis of the modifications of felspar, and sub-divided them into five chief groups—orthoclase, orthoclase and oligoclase, nepheline and leucite, labradorite, anorthite rocks. The orthoclase and oligoclase group was sub-divided into rocks containing quartz and rocks without quartz, and the members of the sub-groups were further distinguished by the presence or absence of hornblende or augite, or of different modifications of felspar. The geological age and the structure (granitic, porphyritic, glassy) afforded additional means of differentiation.

Notwithstanding the great success that attended the microscopic study of rocks, certain mineral elements could not be identified by the finest optical methods, and it was felt necessary to combine microscopic and chemical investigations. Micro-chemical methods were invented for the purpose of testing the composition of minute mineral grains; excellent memoirs dealing with this branch of research were published by Streng, Boricky (1877), Behrens, Haushofer (1883-85), and by Klement and Rénard (1885).

Cordier had in 1815 introduced a mechanical means of separating the fine particles of mineral matter by reducing them to powder, washing the powder with water, and allowing the mineral particles to subside according to their respective specific gravities. An additional device for the isolation of the fine particles was communicated in 1875 by Fouqué, who pulverised specimens of the Santorin lava and then used a strong electro-magnet to attract the mineral particles containing iron.

A more signal improvement in mechanical means of isolation had been suggested in 1862 by Count Schaffgotsch, and afterwards by Church. It was proposed to introduce finely powdered mineral matter into a saturated chemical solution, such as the solution of iodide of mercury and potassium, prepared by Thoulet, and to shake the mineral powder in the solution, so that the particles which are heavier than the solution will sink to the bottom while the lighter particles will float. By diluting the original solution, or using other solutions of given density, the particles can be obtained successively according to their specific gravities. Since Thoulet conducted his experiments, solutions of greater density have been pro-

posed by Klein, Bréon, Rohrbach, and others, and have been used for the purposes of separation.

The important results of microscopical and micro-chemical search were incorporated in the German text-books of Lasaulx (1875) and O. Lang (1877); while the admirable work of Rosenbusch more especially gave an impulse to the study of petrography in other countries. In France, two illustrious petrographers, Fouqué and Michel-Lévy, adopted the improved methods and advanced scientific research by many valuable contributions. From the year 1873, both devoted themselves to the artificial preparation of silicates, and made a comparison of the artificial products with the natural occurrences in rocks; while Fouqué developed principally the crystallographical aspects of microscopic investigations, Michel-Lévy devoted himself more to the microscopic study of the petrographical relations. In 1879, their conjoint work on the French Eruptive Rocks appeared in the form of an explanatory text to the detailed geological map of France.

In this work MM. Fouqué and Michel-Lévy followed the general arrangement of the *Microscopic Physiography* of Rosenbusch. The French authors distinguished original and secondary minerals in rocks; the former are said to be present sometimes as essential, sometimes as accessory constituents; the secondary are sub-divided according to the time of their generation into two main groups, and these are again divided into sub-groups. The rocks are classified with respect to their origin, their geological age, their mineralogical composition, and their structure. The massive rocks of pre-Tertiary epochs are held distinct from those of Tertiary and recent ages, and certain differences are indicated between them. MM. Fouqué and Michel-Lévy recognise two leading types of structure among the massive crystalline rocks, the granitoid and trachytoid; these terms almost correspond to the use of the terms granular-crystalline, and porphyritic in the works of the German petrographers.

The French authors bring into pre-eminence the mutual development attained by the several elements in the rocks. Their special study of this feature has led them to believe that many massive rocks give evidence of the generation of crystals or crystalline material in successive phases of consolidation. In both the granitoid and trachytoid types, the larger crystals are generated during the first phase of consolidation.

A second phase of consolidation is marked by the generation of smaller crystals of microlites or a microlitic ground-mass. The development of crystallites and ground-mass at this phase is limited to trachytoid rocks.

In the case of granitoid rocks the consolidation is complete at the close of the second stage, but in the case of trachytoid rocks there follows still a third phase characterised by processes of alteration in the crystals and matrix already formed, and by the constitution of a micro-felsitic, microlitic or glassy ground-mass.

For the identification of the individual rock-varieties MM. Fouqué and Lévy regard the felspars of primary importance; subordinate means of identification are afforded by the magnesia-iron silicates (mica, hornblende, augite, diallage, hypersthene, peridote). The work concludes with a detailed description of the rock-forming minerals. In France, the Fouqué-Lévy system has held an authoritative place in the teaching of petrography.

A second edition of his *Mikroskopische Physiographie der petrographisch wichtigen Mineralien* was produced by Rosenbusch in 1885. Rosenbusch had practically re-written this work, and made it an exhaustive compendium of all the results obtained by microscopical, crystallographical, and micro-chemical methods. The optical phenomena of crystallography were discussed with the utmost care. In the first edition Rosenbusch had advanced microscopical research by the introduction of new apparatus, in the second he was able to add many valuable mineralogical results of the improved means of research. He also gave full and precise instructions regarding the use of the microscopic methods, so that by following the directions given in this work any earnest student might become a proficient crystallographer and mineralogist.

In 1888, Michel-Lévy and Lacroix published *Les Minéraux des Roches*, a work which provides an excellent general account of all the physical and optical properties of rock-forming minerals, and, like that of Rosenbusch, gives full directions for the optical examination of thin sections, and for all micro-chemical means of identifying mineral fragments. The French authors relied in many cases on the crystallographical investigations of Descloiseaux, and also incorporated many of the methods and results of Rosenbusch.

Although Sorby had been the great pioneer of modern

petrography, the geologists of Great Britain were not to the front in continuing and advancing the new line of research. It was not until Zirkel and Rosenbusch in Germany, and Fouqué, Michel-Lévy, and Lacroix in France, had elaborated the new system of research, and spread its teaching in the universities by their text-books, that Great Britain took a more animated part in the pursuit of petrography.

In 1888, Mr. Frank Rutley published a book on *Rock-forming Minerals*, in which he described the optical and chemical properties displayed by the different minerals on microscopic investigation. In the same year a book on *British Petrography* was published by Mr. J. J. Harris Teall. The chief purpose of the handbook was to bring the newest methods and results of petrological research within the reach of a large circle of British students and geologists. The work deals with the eruptive rocks that occur in Great Britain; it begins with a lucid discussion of ground-mass and the rock elements that cannot be mineralogically identified. Frequent reference is made to the investigations of Sorby and Vogelsang. The chemical composition of the eruptive rocks is fully treated, having respect to the researches of Bunsen. In discussing rock-texture, Mr. Teall attributes great importance to the size and development of the individual mineral components. The features enumerated as valuable for the systematic arrangement of the rocks are (1) the chemical composition, (2) the mineralogical composition, (3) the texture, (4) the occurrence, (5) the origin, (6) the geological age, (7) the locality. As, however, the chemical composition cannot be judged from a hand-specimen, Mr. Teall applies the mineralogical composition as the primary means of classification, and uses texture for the differentiation of sub-groups. The work concludes with very valuable remarks on the origin and the metamorphoses of the crystalline massive rocks.

During the same year Rosenbusch published a second edition of his *Mikroskopische Physiographie der massigen Gesteine*. In this edition he entirely withdrew his former principle of classifying the rocks primarily on the basis of their mineralogical composition. Laying down as a fundamental principle that a natural classification of the rocks ought to reflect the genetic relations, Rosenbusch contended that rock-structure offered the most reliable basis for the construction of a natural system of the massive rocks. He pointed out that the struc-

ture of the eruptive rocks is dependent upon the conditions of their geological occurrence, and classified them accordingly in three chief groups: deep-seated or "plutonic" rocks, intrusive or "dyke" rocks, and eruptive flows or "sheets." This new standpoint assumed by Rosenbusch re-acted upon the whole newer development of petrography. By subordinating in his new system all considerations of the chemical and mineralogical composition, and the geological age, to the mode of occurrence of eruptive rocks in nature, Rosenbusch removed as it were the final judgment of petrography from the laboratory to the field. The petrographer was made to feel that the microscope and chemical re-agents were to be regarded as aids to field observations, but that systematic interest was to be concentrated upon the problems dealing with rock-structure in its relation to particular conditions of stratigraphical occurrence. In this direction original research seemed to give most promise of enlightenment in the immediate future.

Rosenbusch introduced a number of new descriptive terms, *e.g.*, holocrystalline, hemicrystalline, hypidiomorphic, panidiomorphic, etc., for the purpose of defining all structural modifications with scientific accuracy. According to Rosenbusch, the deep-seated eruptive rocks are all distinguished by holocrystalline and hypidiomorphic granular structure. They have originated at great depths of the crust by slow processes of cooling and consolidation. He divides them into sub-groups which are based upon the presence and relative amount of quartz and felspar; in this respect, therefore, Rosenbusch adopted the system of MM. Fouqué and Michel-Lévy.

Rosenbusch includes in his group of intrusive rocks those eruptive masses which occur in the form of typical dykes, yet are to be regarded only as particular facies of deep-seated eruptive rocks, and may probably be associated with the latter in their genesis and their distribution in the crust. The intrusive group is sub-divided into three series—a granitic, a syenitic, and a dioritic, whose characteristic types of structure are quite independent of their mineralogical composition.

Porphyritic structure is said by Rosenbusch to be characteristic of eruptive sheets; the constituents belong to at least two successive generations. He thinks it probable that the older constituents represented by the larger crystalline elements are intra telluric in origin, and may have formed at

great depths previously to any surface eruption of the magma; whereas the younger and minute mineral elements probably originated during the epoch of eruption. With the outflow of a glowing rock-magma at the surface, and the escape of the water vapours, the chemical constitution of the rock-material is changed. The structure of the ground-mass is holocrystalline, hemicrystalline or glassy, according to the more rapid or slower cooling of the magma.

Rosenbusch sub-divides the rocks of eruptive flows into *palæovolcanic* (porphyry, porphyrite, augite porphyrite, melaphyre, and picrite porphyrite) and *neovolcanic* (liparite, trachyte, phonolite, andesite, basalt, etc.). Some of the older flows, such as the diabase porphyrite and picrite porphyrite, resemble granitic-porphyritic intrusive rocks so closely that they seem to bear the same relationship to them which the typical intrusive rocks bear to the plutonic or deep-seated masses. They may be distinguished from true eruptive flows by the absence of tuffs.

The new classificatory scheme of Rosenbusch showed quite clearly that he had been strongly influenced by the views of MM. Fouqué and Michel-Lévy, and these two French petrographers felt it incumbent to declare the position they assumed towards it. In 1889, Michel-Lévy discussed the work of Rosenbusch in a special memoir,[1] agreeing with many of its principles, but disputing others. Regarding the sub-division of the eruptive rocks into deep-seated masses, intrusions, and flows, Lévy points out that the intrusive group is quite artificial and untenable, as intrusions may either take the form of narrow vertical dykes or almost horizontal sheets or "sills." He also contests the conclusion of Rosenbusch that only one generation of the crystalline constituents took place in the deep-seated rocks, a group which almost precisely corresponded with the granitoid group of MM. Fouqué and Lévy.

In Michel-Lévy's opinion, the geological aspects and associations of the eruptive rocks, as well as the geological age, have too little connection with the structure of the rocks to provide a good basis of classification. Michel-Lévy cites cases where rocks belonging to the "deep-seated group" of Rosenbusch, *e.g.*, granite, ophite, and gabbro, occur in the form of eruptive sheets. According to Michel-Lévy, the different types of structure in eruptive rocks are due to variations of temperature

and pressure, and the saturation of the magma with gases and heated vapours. The latter play the chief *rôle* in the acid rocks, producing pegmatitic, micro-pegmatitic, and other structural types, and also determining a definite sequence of eruption. On the other hand, the structure of the basic rocks depends almost exclusively on temperature, *i.e.*, on the greater or less rapidity of the process of cooling.

After this adverse criticism of the classification advanced by Rosenbusch, Michel-Lévy proceeds to discuss the varieties of rock-structure, and shows the frequent agreement between the views of Rosenbusch and his own; he also points out that the differences of nomenclature are more apparent than real, and tries to bring the French and German terminology into harmony by means of a list of synonyms. In most cases, Michel-Lévy claims the priority for his own terms.

Only a few minerals come into question in the composition of eruptive rocks. Fouqué and Michel-Lévy had classed these minerals as original and secondary, sub-dividing the secondary minerals in groups corresponding with the order of formation. According to Rosenbusch, there are just two fundamental laws controlling the order of formation—the one, that the magma is always more acid than the sum of the mineral constituents already solidified in it; and the other, that the separation of the elements which occur in less profusion has generally been concluded before the separation of the more richly distributed elements takes place. Michel-Lévy questions the correctness of these laws, and makes an elaborate inquiry into the order of separation of the mineral constituents. He devises a code of symbols by which the structure, composition, and genesis of the massive rocks may be represented by a short formula; and finally arrives at the conclusion that the classification and the nomenclature of eruptive rocks must be kept free from any hypothesis regarding their origin, and consequently that structure and mineralogical composition form the only basis of a rational classification.

Zirkel assumed a similar standpoint in the second edition of his *Lehrbuch der Petrographie* (1893-94). This large three-volume work is the only complete handbook of petrography. All varieties of eruptive, schistose, and sedimentary rocks are treated according to their macroscopic, microscopic, and chemical constitution, their structure, and their geological

occurrence. The diction is clear, the previous literature of petrography has been completely mastered, and its results are fully incorporated, the historical development of the different branches of the study being carefully indicated throughout the work. The lack of illustrations has been deplored by many, but the addition of plates would have rendered the work much more expensive.

The first volume begins with a detailed account of all methods of investigation applied in modern petrography. Rock-forming minerals are then described according to their morphological, optical, physical, and chemical properties so far as these are important for petrography. In discussing the structure of rocks, Zirkel frequently dissents from the terminology of Rosenbusch; at the same time he endeavours to establish the terms which had been applied in his own text-book.

The special petrographical part of the work starts with the treatment of the massive rocks formed by the cooling and consolidation of molten magmas. The geological occurrence, the composition, the macroscopical and microscopical features of their structure, are elucidated. The difficult questions concerning ground-masses are then brought forward, and finally the laboratory experiments are described by means of which chemists and geologists have tried to produce different kinds of massive rocks artificially.

Zirkel contests the principle of classification adopted by Rosenbusch, and adduces weighty arguments to show that the group of "intrusive" or "dyke" rocks is intenable. He adheres to the principle of mineralogical composition as the true basis of classification, and draws up a Classification Table on the same lines as he had followed in the first edition of his text-book. Zirkel's sub-divisions agree in many respects with those of Fouqué and Michel-Lévy. Taking the felspathic constituents as the chief standard, Zirkel distinguishes two felspar-bearing groups, a potash-felspar group, and a soda-lime felspar group; also a third group, free from felspar, and comprising the nepheline, leucite, melilite rocks.

Like Michel-Lévy, Zirkel distinguishes two leading types of structure: 1, uniformly granular; 2, porphyritic and glassy rocks. Deep-seated rocks of various geological ages belong to the granular or granitic type; while eruptive flows may be *either* porphyritic or glassy, and they may be sub-divided

according to age as pre-Tertiary (Palæovolcanic), and Tertiary and Post-Tertiary (Neovolcanic).

The second and third volumes of the text-book are devoted to an exhaustive description of the individual varieties of massive and schistose crystalline rocks and the sedimentary rocks.

Zirkel's text-book will always remain a fundamental work in petrography. While the macroscopic methods of the older teaching are still predominant in the first edition of the work, the second edition is at once a frank and full acknowledgment of the petrographical reform necessitated by microscopic and micro-chemical methods, and a convincing witness of the rapid and remarkable success which had crowned the labours of petrographers in the new field of research.

During the last few years the discrepancy between the views of Zirkel and Rosenbusch has increased. Rosenbusch, in the third edition of his *Physiographie der massigen Gesteine* (1896), and also in his *Elementen der Gesteinslehre* (1898), has adhered to the standpoint which he assumed in 1888, and has rejected Zirkel's objections. The differences between the two leading German petrographers refer in no sense, however, to the methods of investigation, but expressly concern the inductive conclusions at which they have arrived regarding the genesis of the eruptive rocks, and the best system of classification. The rapid progress of petrography is one of the greatest acquisitions made to science during the latter half of the nineteenth century, and has elevated petrography to the rank of a thoroughly established branch of natural philosophy.

As the microscope revealed more and more fully the fine structure and microscopic elements of rocks, the traditional conceptions of geologists regarding the origin of the rocks were gradually undermined. The old strife between Plutonists and Neptunists had collapsed when the Neptunists admitted the volcanic origin of basalt and the "trap" series of rocks. The handsome monograph published by C. C. von Leonhard in 1832 had conclusively proved the agreement of basalt with true volcanic rocks, both in the geological occurrence of the basalt and in the contact phenomena produced at its margins. Thanks to the observations of Humboldt, Buch, Poulett-Scrope and others, not only was the volcanic origin of basalt, trachyte, trap, porphyry, mela-

phyre, phonolite, and related rocks generally recognised, but also Huttonian views respecting the plutonic origin of the granite-grained massive rocks became more widely accepted.

Nevertheless, new objections were raised against the pyrogenetic origin of the granite-grained rocks. Keilhau asserted in his work on the "transitional formations" of Norway that the granite in that area had originated from the conversion of clay slates. The Munich chemist, Johann Fuchs, in 1837 attacked the doctrine of pyrogenetic origin in a series of papers entitled *Ueber die Theorien der Erde*. He pointed out that fusion experiments had never succeeded in reproducing granitic rock artificially, even although individual elements of the rock had been obtained; further, minerals having different melting-points were present in granite, yet these minerals had not consolidated from the magma in the order that corresponded with that of their fusibility, therefore he argued it was absolutely erroneous to suppose that granitic rock had formed merely as the result of slow cooling and consolidation. Fuchs advanced the view that granite, and the granitoid rocks generally, had consolidated from an amorphous magma saturated with water.

In 1845, Schafhäutl succeeded in reproducing quartz artificially by the application of superheated water in a Papin crucible, and this result seemed to confirm Fuchs' views. On the other hand, Fournet, in 1844 and 1847, pointed out that there were certain conditions under which the fusing-points of substances were lowered to temperatures much below the points at which they usually solidified. In papers written about the same time, Durocher, referring for support to Fournet's *Theory of surfusion*, supposes a mass of granite to be originally a homogeneous magma, which can remain fluid until the fusion temperature of felspar is almost reached. At about 1500° C. the separation of felspar, quartz, and mica begins, and the different minerals solidify according to their tendency to crystallisation. Durocher thinks the later formation of quartz crystals might in this way be explained, since felspar passes more readily than quartz from the viscous to the solid state.

Scheerer, the illustrious chemist and geologist, offered formidable objections to the purely pyrogenetic origin of granite in a memoir published in the *Bulletin* of the French

Geological Society in 1847. His chief arguments were: (1) the occurrence of separated quartz; this, according to Scheerer, is impossible in the case of consolidation from a fluid mixture of silicates; (2) the order of succession in the separation of felspar and quartz; Scheerer ascribes no weight to Fournet's "surfusion" theory, which supposes that quartz can remain longer in solution than the more easily fusible felspar, as this is a hypothesis which has not been tested experimentally for silicate mixtures; (3) the presence of so-called pyrognomic minerals (orthite, gadolinite), whose physical properties are altered at comparatively low temperatures.

Scheerer also drew attention to the fact that water is held in chemical combination with several of the constituents of granite. This water he regarded as originally present in the magma from which the granite solidified. But if the magma, as might be safely assumed, was subjected to high pressure, which prevented the escape of the superheated water, then very probably the influence of the water might enable the granite magma to remain fluid at temperatures much lower than would be the case under the influence of dry heat. When solidification set in, the minerals with the strongest tendency to crystallise were the first to separate from the pasty granite mass, and the water concentrated itself in the remaining ground-mass, which always became more acid, and owing to the superfluity of water the separation of quartz and the pyrognomic minerals might under some circumstances be suspended until the temperature of the mass was below that of a red heat.

Although Durocher still upheld the pyrogenetic origin of granite against the objections raised by Scheerer, the hydato-pyrogenetic or aquo-igneous doctrine of Scheerer rapidly gained ground in literature. Probably its strongest antagonist was Bischof, whose explanation of the origin of granite, syenite, porphyry, and even basalt, showed a reversion to Neptunistic teaching. In the second volume of his *Physical and Chemical Geology* (1851), Bischof, after a full discussion of the rock-forming minerals, came to the conclusion that all except augite and leucite could take origin from aqueous solutions without increased temperature and under normal pressure, and that their origin from fused rock-masses was quite exceptional. Moreover, the resemblance between the composition of many eruptive rocks and that of certain sedimentary rocks

(slate, greywacke), as well as the interbedding of granite with gneiss and sedimentary schists, led Bischof to agree with the opinion of Keilhau (1825) and Virlet d'Aoust (1846), that granite and syenite represented altered clay slates. Diabase and even melaphyre and basalt were regarded by Bischof as shales and clays, poor in silica, and altered by the agency of water.

C. W. C. Fuchs, in 1862, supported Bischof's views in a valuable treatise on the mineralogical and chemical constitution of the granite in the Harz mountains. He regarded the granite as a product of the alteration of sedimentary greywacke by means of water, hornstone being formed in the earlier phases of alteration, and granite during the later phases; these two rocks were connected by a transitional series of alteration products.

A serious objection to the pyrogenetic origin of granite was advanced by H. Rose in 1859. He showed that after fusion quartz passes into an amorphous modification of silica, thereby changing its specific gravity from 2.6 to 2.2. As the quartz in granite and granitoid rocks always has a specific gravity of 2.6, it seemed impossible to suppose it had merely separated from a dry fused mass.

The aquo-igneous origin of granite suggested by Scheerer on theoretical grounds was soon to receive an experimental conformation. Struck by the peculiar changes which sedimentary deposits underwent in contact with, or in the near vicinity of, eruptive rocks, Professor Daubrée attempted to show that neither heat alone, as Hutton had supposed, nor vapours and gases would suffice to call forth these changes, but that superheated water under great pressure was the most important agent in the metamorphism of rocks. To prove this hypothesis, Daubrée in 1857 conducted a series of very instructive experiments. A glass tube partially filled with water, and hermetically sealed at both ends, was placed in a strong iron tube, which was then closed and exposed to a temperature slightly below red heat. After a few days the glass tube was attacked; in parts of it a finely laminated structure was induced, and the whole tube was transformed into a zeolitic mineral, in virtue of the removal of silica, alumina and soda, and the addition of water. Innumerable small crystals of quartz formed; microlites and diopside crystallites developed in abundance in the less violently attacked parts of the tube,

and spherulitic structure was present in some places. In other experiments where Daubrée applied superheated steam, he obtained orthoclase and a micaceous substance. These experiments gave convincing evidence that the constituents of granite could be of aquo-igneous origin.

Almost simultaneously with Daubrée's investigations, Sorby was engaged in microscopic examination of thin sections of granite. He demonstrated, in 1858, the presence of water vesicles in quartz, and concluded that the granite magma had been saturated with water and had solidified under great pressure at a temperature not above a dull red glow. Delesse, in 1857, drew attention to the great differences between the phenomena of contact metamorphism produced by granite and those produced by lavas, and argued from his observations that the granites had not solidified from a state of dry fusion, but from an eminently plastic magma, whose plasticity was due to the presence of water under high pressure. The theory of the aquo-igneous origin of granite, and of the granite-grained massive rocks generally, began to win wider credence in geological circles.

The rapid progress made by microscopic research after the year 1860 entirely disproved all theories which had assumed an aqueous origin for porphyritic rocks. Examination of thin sections showed conclusively that basalt, phonolite, trachyte, porphyry, etc., were identical in internal structure and composition with true volcanic lavas. Corroborative evidence was afforded by the experimental researches which were conducted, more especially in France, with such eminent success. The attempts to reproduce rock-forming minerals artificially proved that the majority of the constituents in the granitic rocks, such as quartz, orthoclase, microcline, potash mica, tourmaline, hornblende, could be solidified from fused materials by the admixture of water vapours, chlorine, and other solvents, whereas the minerals occurring in volcanic and porphyritic rocks, such as olivine, augite, enstatite, hypersthene, wollastonite, the plagioclase varieties, melilite, nepheline, leucite, magnesia mica, garnet, magnetite, spinel, hæmatite, tridymite, etc., could solidify from a state of dry fusion.

In the year 1878, the efforts of Fouqué and Michel-Lévy to reproduce eruptive rock without the aid of superheated water were at last successful. The chemical elements were placed in

a platinum crucible and fused; the fused mass was then subjected for forty-eight hours to a temperature nearly that of the fusing-point, the material being afterwards allowed to cool slowly. According to the ingredients that were introduced, consolidated rock-material agreed completely with certain augite-andesites, leucite and nepheline rocks, and contained the majority of the minerals composing these rocks in the form of well-developed crystals.

Inasmuch as these important results showed that the porphyritic series of rocks could originate merely by the cooling of a molten magma, they tended to widen the gulf between the porphyritic and basaltic, and the granite-grained series. Favour was given to Hutton's assumption that the latter owed their distinctive characters to their subterraneous origin under great pressure, and the Huttonian conception was made even more emphatic by Rosenbusch in his classification of 1886. Further confirmation was given by Gilbert's description of intrusive masses of rock, so-called "laccolites" (*ante*, p. 274) between sedimentary strata in the Henry mountains; and also by Reyer's investigations on massive flows and local differences in the mineralogical composition and the texture of the consolidated rock.

After the principle of the eruptive origin of the crystalline massive rocks had been firmly established, the interest of petrographers was directed to the investigation of the chemical constitution of the rock-magmas and the processes effecting their consolidation. The chemistry of rocks had been greatly advanced by the researches of Abich, Delesse, Bischof, and especially by Bunsen. As has been already mentioned (*ante*, p. 328), Bunsen concluded from his examination of the igneous rocks of Iceland that all the eruptive rocks of that island in their composition presented either a normal trachyte magma or a normal pyroxene magma, or a mixture of these two varieties of rock-magma in varying proportions. According to Bunsen, it is possible by means of a simple formula, being given the amount of silica present in such a mixed rock, to reckon the amount of the normal trachytic and normal pyroxenic material present in the rock. Streng, Kjerulf, and others accepted Bunsen's conclusions and tried to apply them generally to all eruptive rocks.

Sartorius von Waltershausen explained (1853) the chemical difference of the Iceland eruptive rocks, not upon Bunsen's

theory of their origin from two different subterranean localities, but upon the assumption of their origin at different depths of the crust. He held as a general principle that subterranean magmas are distributed in the crust according to their specific weight, the lighter magmas rich in silica occupying the crust-cavities in the higher zones, the heavier basic magmas occurring at lower horizons. Durocher, in 1857, gave a similar explanation of the chemical and mineralogical differences in rock-magmas.

On the other hand, Poulett-Scrope (1825), Darwin (1844), and Dana (1849) attributed the varieties of eruptive rocks to the subsequent division and differentiation of a homogeneous primitive magma. Justus Roth (1869) also regarded all plutonic rocks as having been derived from a uniform primitive magma, and explained their present differences of constitution as a result of the different rates of cooling. Iddings more recently remarked on the fundamental mineralogical affinity of the different rock varieties in an eruptive district, and compared such resemblances with the blood relationships of organisms. Although most geologists at the present day incline to the opinion that the different facies of eruptive rock represent portions of a single primitive magma, there is still great variance of opinion regarding the mode of division and differentiation.

The experiments of Spallanzani, Hall, and Bischof showed that by means of regulating the process of cooling, or by the application of different degrees of pressure, fused silicate mixtures could be obtained in glassy, slaggy, or crystalline rock-form. By Daubrée's experiments it was ascertained that the conditions requisite for the artificial reproduction of granite-grained eruptive rocks were a moderate temperature and the presence of water vapour. Again, the experiments of Fouqué and Lévy seemed to show that the younger eruptive flows with porphyritic structure had solidified slowly from an igneous magma. It has proved a very complex and difficult question to find out what determines the particular sequence in which the rock-forming minerals separate from a viscous magma. Fournet and Bunsen showed that the minerals by no means separated from the magma in the order of their fusing-points. After various attempts to solve the problem by direct methods, it was then approached indirectly: keeping in view the essential constituents of any particular rock, attempts

were made to separate from them any mineral elements which were foreign to the rock, or had come into the magma before it solidified, and also all secondary elements which had formed after the consolidation of the rock during the processes of internal decomposition or interaction.

Excellent work has been done in this field of research by Roth, Bischof, Delesse, Zirkel, Broegger, and Iddings.

Certain principles are usually inculcated regarding the sequence in which the minerals take origin during the passage of a magma from the viscous to the solid state, but the principles are by no means always applicable, and have therefore frequently been contested. Minerals which have crystallised with the most complete and perfect form have usually been regarded as the first-formed, while those which appear to have been checked in their proper development by others, have been regarded as of later formation. Again, minerals that are enclosed within other minerals are usually taken to be older than the enveloping material, yet cases are cited where they are really younger, having separated out from a portion of the magma enclosed within the developing mineral. Minerals without any inclusions for the most part belong to the first generation of solid material. If two minerals occur as intergrowths with one another, contemporaneous generation is indicated. In rocks with porphyritic structure the larger mineral forms are as a rule older than the ground-mass.

It was in accordance with these principles that Fouqué and Michel-Lévy first distinguished different generations of minerals, and used the number of the mineral generations as a distinguishing feature between rocks of granitic and porphyritic structure. Through a large number of individual observations it has been possible to determine genetic series for the rock-forming minerals. Certain minerals, such as magnetite, titanite, rutile, apatite, zircon, spinel, olivine, belong generally to the earliest products of separation, preceding the augites, hornblendes, felspars, and quartz. Rosenbusch holds the opinion that in the deep-seated rocks, at any one interval of time, there is only one kind of mineral separated from the magma. The periods of formation for the different constituents succeed each other so that either those of one kind do not form until the complete separation of the preceding kind; or much more frequently, a younger constituent in order of separation begins to form a certain time before the completion of the

next oldest constituent. In general, solidification begins with the crystallisation of the ores and accessory constituents, then follows the formation of the coloured silicates (olivine, mica, augite, hornblende, etc.), then that of the felspathic minerals, and finally that of free silica. In the rocks of eruptive flows the more basic constituents crystallise out before the less basic, so that at any period during the consolidation the sum of the constituents already crystallised out from the magma is more basic than the remaining portion of the magma. Mr. Teall assumes that in the rocks with a large or medium amount of silica, the dissolved constituents represent a so-called "eutectic" mixture, and as such can remain unchanged at a temperature which is below their melting-point. But if they do not occur in the definite eutectic relations, the overplus of substances continues to separate out until the eutectic mixture is attained.

In an important memoir (1887) on the crystallisation of igneous rocks, Lagorio classified the porphyritic flows according to the amount of silica in five grades, and gave the results of chemical analyses of the ground-mass. He arrived at the conclusion that the separation of the minerals in an eruptive magma depends almost entirely on the chemical composition of the magma, as well as on the affinities and internal movements within the mass; whereas pressure and high temperature exert only a subordinate influence.

Iddings in 1889, in a paper on the same subject, expressed views in many respects similar to those of Lagorio, but ascribed greater importance to the influences of pressure and temperature in regulating the rate and processes of cooling; he thinks the local conditions of pressure and temperature mainly determine the structural differences which often exist at different portions of a continuous mass of eruptive rock, and explain why a superficial portion may display porphyritic structure while the deep-seated portion is granite-grained.

There are abundant examples of transitional rock-varieties in eruptive bosses and sheets. As far back as 1852, Delesse showed that the Ballon d'Alsace in the Vosges mountains consists of hornblendic granite in its central portion and its summit, but towards its peripheral portions passes into syenite and finally into diorite. More recently, in 1887, similar facts were demonstrated by Barrois in his brilliant account of the eruptive rocks in Brittany. The researches of Barrois have

already become classic; generally speaking, they go to show that the mineralogical character of the stratified rocks as affecting the conduction of heat and the relative pressures between the bedded rocks and the intruded igneous rock-material, influenced the subsequent processes of consolidation in the latter, and determined the orientation of crystals and the modifications of structure.

In many active and extinct volcanoes, it would appear that the character of the ejected rock-material gradually alters with each successive eruption, so that the first and the last products of eruption represent the extremes of a petrographical series. In the Rocky mountains, and in the Sierra Nevada, Baron von Richthofen (1868) recognised a definite sequence of propylite, andesite, trachyte, rhyolite, and basalt, and his observations have since been confirmed by American geologists. The more recent works of Professor Broegger on the eruptive district of Southern Norway have extended the observations so ably initiated by Baron von Richthofen. Professor Broegger has given an admirable exposition of the eruptive rocks in that district with respect to their mineralogical, structural, and chemical constitution, their geological occurrence, their eruptive sequence, the division and differentiation of the original magma.

In the year 1890, Professor Broegger contributed a paper to the *Zeitschrift für Krystallographie und Mineralogie*, in which he sub-divided the eruptive rocks in the neighbourhood of Christiania into two chief series, an older and a younger, the younger containing only basic intrusive rocks (diabases), the older comprising very different acid and basic rocks, which may be again sub-divided into five groups according to their mineralogical and chemical composition. All the products of this older group form a transitional series of rocks passing petrographically into one another, and closely related chemically. They have clearly proceeded from an originally continuous molten mass which has been segmented, and has undergone differentiation into several rock-types. The oldest members of the genetic series are basic, the youngest strongly acid. In the opinion of Broegger, the original magma was an aquo-igneous solution of silicates, and rich in soda. Towards the close of the Devonian epoch, the first fissure eruptions took place, the magma being still fairly basic, and these were succeeded from time to time by outbreaks of increasingly acid

magma. The various magmas solidified sometimes underground as laccolites, sometimes as dykes, sometimes as superficial flows, and induced contact-metamorphism of diverse characters. Broegger could not determine any definite sequence in the separation of the component minerals, but was able to add many observations bearing upon this point.

A later publication by the same author is entitled *The Eruptive Rocks of the Christiania District*, and comprises two volumes. The first, published in 1894, is devoted to the rocks of the Grorudite-Tinguaite series. Broegger thinks these take an intermediate position between deep-seated bosses and eruptive flows, and represent members of a connected series of protrusions from the same magma, which either solidified underground in massive form or occupied crust-fissures.

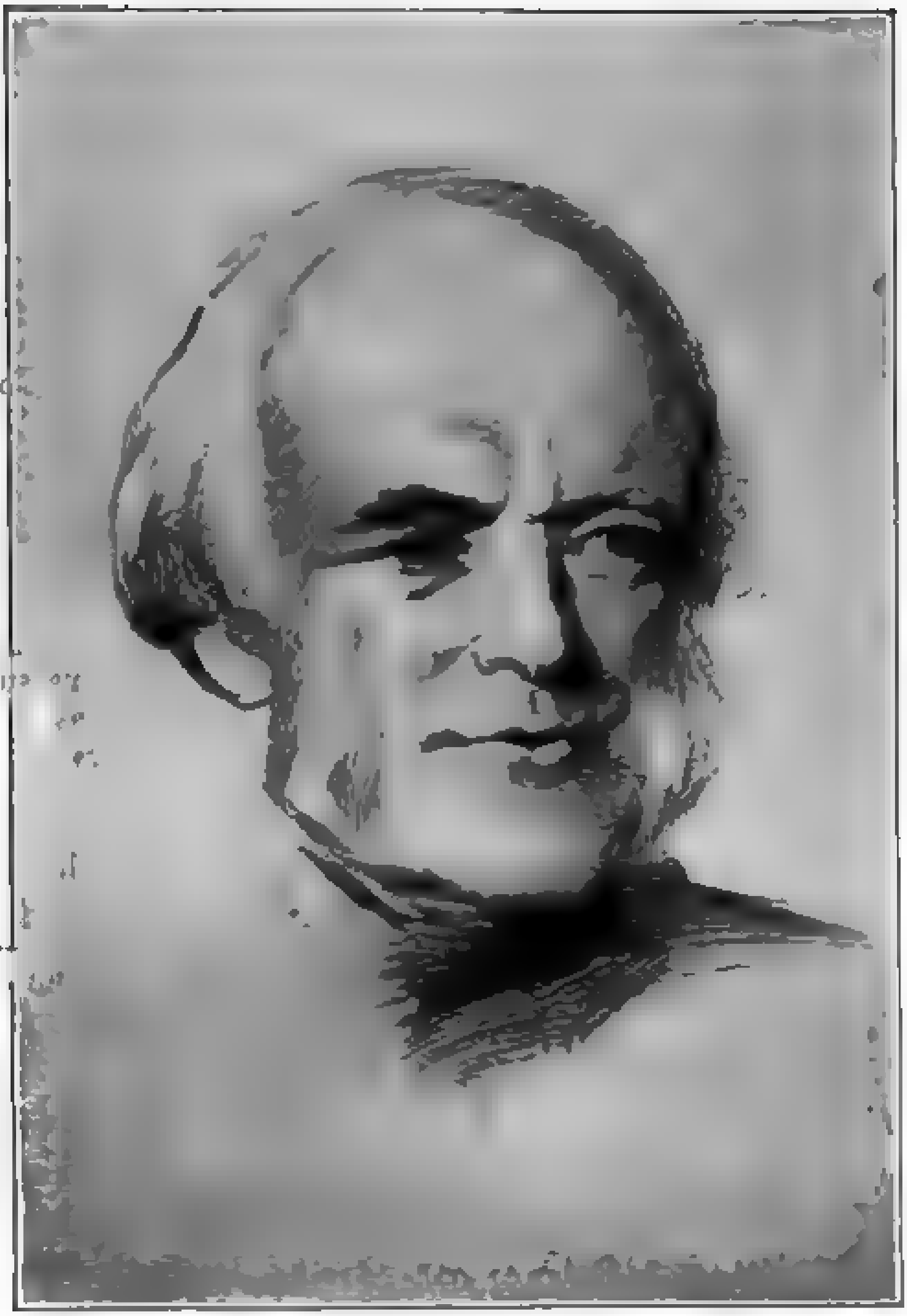
The second volume, published in 1895, instituted a comparison between the succession of eruptive rocks in the Christiania district and that in the eruptive district of Monzoni and Predazzo in South Tyrol. On the basis of his own observations in both districts, Broegger explains the famous Triassic monzonite, granite, and hypersthenite as deep-seated laccolitic expansions of the eruptive flows in the same neighbourhood (melaphyre, augite, porphyrite, and plagioclase porphyrite), and views them as a series of differentiations from an originally uniform magma, analogous with the differentiations presented in the Christiania district.

From the foregoing pages it is apparent that Rosenbusch, Broegger, Iddings, Williams, and others are inclined to minimise the petrographical contrast between the so-called plutonic and volcanic rocks, and to recognise in underground and superficial occurrences of eruptive rock only different facies of the same magma, consolidated under different conditions. On the other hand, Zirkel (1893) strongly emphasised the differences between the granitic, deep-seated rocks and the porphyritic or glassy flows, and brings forward many objections to the laws enunciated by Rosenbusch regarding the successive separation of minerals from fused masses. In general, petrographers may be said to be still actively investigating the ground-masses, in the study of which there are many problems awaiting solution.

Microscopic researches have fully elucidated the composition and the origin of the sedimentary strata. There is no longer

any difference of opinion regarding the derivation of the rock-material composing stratified deposits—on the one hand from the fragmented and finely triturated products of surface denudation or from the chemical activities of infiltrating water in the crust, and on the other, from the accumulation of organic deposits. But the origin of gneisses and the crystalline schists is still shrouded in mystery; much is known, but far more remains to be discovered. These rocks used to be regarded as the fundamental rock-formation of the sedimentary succession; the lowest member of the group being usually gneiss or coarsely foliated and banded granitic rock, and the uppermost usually phyllite or finely foliated lustrous, slaty rock. In the eighteenth century, three leading hypotheses were promulgated in explanation of the origin of these rocks. One theory (supported by Buffon, Breislak, and others) regarded the gneisses and the crystalline schists as the fundamental rocks of the earth's crust, the product of the first consolidation of molten rock material on the cooling surface of the earth; the Wernerian theory represented them as the oldest chemical precipitates from the primæval aqueous envelope of the earth, possessing a crystalline texture in virtue of the high temperature at the earth's surface in the primæval epoch; Hutton regarded them as normal sedimentary deposits, not necessarily of the primæval epoch, which had been carried to greater depths in the crust after their deposition, and there been melted, metamorphosed, and rendered crystalline by the combined influence of the earth's internal heat and enormous crust-pressure. In his conception of the relation of dynamic agencies to rock-deformation, Hutton was far ahead of his contemporaries, and the nineteenth century was well advanced before Darwin, Poulett-Scrope, Sharpe, and a few of the keenest observers began to apply the principle of dynamic agencies of deformation in the earth's crust. Beroldingen explained gneiss as regenerated granite. Although with certain modifications, each of these hypotheses claims supporters at the present day.

In 1822 Ami Boué, in his geognostic description of Scotland, modified the Huttonian hypothesis in so far as he thought that in addition to subterranean heat and pressure, the action of vapours and gases had played a part in the metamorphosis of sedimentary deposits to crystalline rock. The Norwegian geologist, Keilhau, in the following year advanced his view that a foliated structure had been superinduced upon crystal-



SIR C. LYELL.

From a Photo by Walker & Cockerell, London, E.C., of a Painting by G. Richmond, R.A.

line schists, in common with most of the older massive rocks, by the agency of water, without the aid either of pressure or of increased temperature. During the years 1826-28, Studer and Élie de Beaumont made the observation in the Swiss and Savoy Alps that gneiss and micaceous schists repose upon unaltered sedimentary strata, and that in certain crystalline schists fossils are present which prove them to belong to relatively young geological epochs. This discovery was a very great blow to the geologists who upheld the hypothesis of the Archæan or pre-Cambrian age of all gneisses and schists. Studer suggested some time later (1855) that the transformation of these schists had proceeded not outward from the lower horizons to the upper, but possibly inward from younger and outer horizons of rock to deeper crust-levels. Hoffmann, who had in 1830 observed crystalline schists interbedded with conglomerates and coarse grits of the "transitional" series, advocated the view that the stratified grits and conglomerates represented unaltered patches, and the gneiss and schists represented altered portions of one and the same geological formation.

Lyell accepted the Huttonian hypothesis in its essential features, and the wide circulation of his principles gave Hutton's teaching greater currency abroad. In addition to heat and pressure, Lyell thought electrical and other agencies might have combined to render the sedimentary structures semi-fluid, the rock material having then been re-arranged; traces of organisms disappeared, but the bedding-planes for the most part persisted. Lyell taught that gneiss and micaceous schist represented sandstones which had been altered by contact with eruptive rocks, argillaceous schists had been originally shales, and marble represented limestone that had been rendered crystalline. In accordance with the Huttonian doctrine that the high temperature had acted outward through the crust, the lowest schists and gneisses were said by Lyell to be those which had suffered the greatest degree of metamorphism. At the same time, under certain circumstances comparatively young deposits might be metamorphosed, and it could by no means be assumed that all crystalline schists must belong to the fundamental or Archæan rocks. It was Sir Charles Lyell who gave to the group of gneiss and crystalline schists the name of "metamorphic" rock, and the name was rapidly adopted in the special literature of geology and in text-books.

Élie de Beaumont was the first to point out the contrast between widespread or normal metamorphism and the contact metamorphism which was limited to smaller zones of rock, and especially to the contiguous parts of eruptive and sedimentary rocks. Daubrée afterwards applied the term of regional metamorphism to distinguish these processes which had acted throughout vast regions of the crust and altered thick formations of rock.

One of the extreme Neptunists was Johann Fuchs, who explained the crystalline schists, gneiss, granitic and porphyritic rocks as segregation products from a watery or pasty material. The American geologist, Professor Dana, in 1843 thought that the Huttonian doctrine did not attach sufficient importance to the agency of heated water in effecting rock-metamorphism. He compared gneiss with volcanic tuffs, and held the opinion that during invasions of granitic magma into the upper zones of the crust a granitic ash also escaped, and under the influence of superheated water became caked and cemented into the form of gneissose and schistose rocks. J. Bischof, in several papers published between the years 1847 and 1854, agreed with Keilhau in assuming that the oldest sediments were for a long time supersaturated with water, and that chemical changes had slowly altered their constitution, converting argillaceous sediments first into clay-slate, and by continuance of the chemical processes into micaceous schists.

Scheerer contributed in 1847 a suggestive paper on the origin of gneiss, in which he took the standpoint that it might be produced in various ways and from various rocks. He explained the gneiss of the Erz mountains as a rock that had been metamorphosed from sedimentary strata *in situ*, whereas the red gneiss during the time of its metamorphism had undergone flow movements comparable to those of an eruptive magma. Again, in many cases gneiss was a fundamental Archæan rock representing a portion of the primæval crust of the earth. Cotta also thought that most gneiss had formed part of the original crust, but he regarded the crystalline schists as the culminating result of a process of metamorphism undergone by all sedimentary rocks which had already been, or were now in process of being, covered by a thick mantle of younger deposits. The change, he thought, had been effected by heat and pressure, possibly in combination with water; and although the crystalline schists were in many places now ex-

posed at the surface, they must have been subsequently elevated to that position, and the superincumbent rocks have been removed by denudation. Naumann supported the view that most gneiss and crystalline schists represented the oldest rock-sediments, but he agreed with Poulett-Scrope, Darwin, Fournet, Cotta, and others that many gneisses had been produced by the deformation of eruptive rocks, and those might be of different ages. A similar standpoint was afterwards taken by Kjerulf and by Lehmann, the author of an excellent work (1884) on the ancient crystalline schists, with special reference to the metamorphic rocks of the Erz mountains, Fichtel mountains, the mountains of Saxony and of the Bavarian and Bohemian frontiers.

Delesse in 1861 declared himself an adherent of the metamorphic doctrines, and ascribed rock-metamorphism to high temperature, water, pressure, and molecular movements. In his opinion, after the first crust formed on the cooled surface of the earth-magma, it was violently attacked by the action of the condensed vapours and afforded material for a great accumulation of sediments. The metamorphism of these oldest sediments produced gneiss and the crystalline schists, and these could again become plastic and be transformed into plutonic rocks. Thus Delesse assumed the deep-seated granite series to have been produced by the re-melting and re-solidifying of metamorphosed sediments. He was supported in this view by Daubrée (1857). According to Daubrée, the first-formed crust was saturated with the water of the primitive ocean, and the mineral constituents of gneiss and the oldest crystalline schists separated out from a pulpy, softened mass. The younger schists (chlorite schist, mica schist, phyllite) of the primæval mountain-systems were thought by Daubrée to be pre-Cambrian deposits metamorphosed by pressure and superheated water. The metamorphism of the younger Alpine schists was also referred by Daubrée to the same influences.

Sterry Hunt similarly held that the crystalline schists represented the earliest chemical deposits. He thought they owed their planes of schistosity to the contemporaneous effect of intense heat combined with the action of water and pressure. He tried to elucidate the chemical processes of separation, to determine an order of deposition, and even to demonstrate that the eruptive rocks were also metamorphosed sediments, which after having been made plastic penetrated

the sediments above and assumed the form of eruptive massive protrusions.

The microscopic examination of micaceous schist led Sorby (1856) to the assumption that it had originally been a shale and had been altered probably by means of water, a high temperature, and crust pressure. He regarded the foliated structure as a result of mechanical pressure. Hitchcock, in 1861, also emphasised the action of mechanical strains.

Sir William Logan's discovery, in 1867, of the thick series of gneisses and schists forming the floor of the sedimentary succession in Labrador and Canada, gave for a time additional support to the view of the Archæan age of all metamorphic rocks; but every year stratigraphical researches were bringing new facts to light which could not harmonise with this simpler view of one primæval epoch of formation for the crystalline foliated rocks.

Zirkel, in 1866, made a complete *resumé* of the literature on the subject of the metamorphic gneiss, and after a careful criticism of the facts and arguments, concluded that there is probably an original gneiss and a metamorphic gneiss. Water and the plastic magma have participated in the formation of the former; it formed the first solid crust, and could, under certain circumstances, especially in the immediate vicinity of granite, partake of its eruptive character. Gneiss has either taken origin from shales and grits by contact metamorphism in the presence of heated water, or has arisen from the subterranean transformation of sedimentary strata by means of some simple processes of water-permeation, which have so far eluded discovery. Zirkel also explains the origin of granulite and the other crystalline schists upon principles of water-permeation, but he regards micaceous and chloritic schists and phyllites as metamorphosed sediments.

Lossen initiated a new departure in the investigation of the metamorphic group, in so far as he succeeded in impressing geologists with the high value of accurate field investigations in assisting the solution of some of the intricate problems of metamorphism. During his examination of the Taunus mountains (1867), Lossen formed the opinion that most of the crystalline schists had originated as sedimentary strata containing a large amount of interstitial water, and had been cleaved and altered by the action of strong dynamic pressures during the mountain-making movements. Gneiss and mica

schists had been, he thought, parts of the original granitic crust of consolidation, which had been similarly converted by pressure-metamorphism into banded, foliated, and cleaved rock-facies. Lossen subsequently examined and mapped the Harz mountains geologically, and found further confirmation of his theory of "dislocation metamorphism." He demonstrated in the Harz mountains that the same rocks which extended over wide regions as ordinary shaly sediments could be traced into a zone of crust disturbance, where they became crystalline and schistose, and were split by planes of cleavage superinduced upon the rock-strata at various angles with the planes of stratification. Although Lossen's work threw a new interest into phenomena of cleavage, the presence of cleavage-planes had long been known in certain rocks. As far back as the eighteenth century, Lasius and Voigt had drawn attention to the difference between the planes of stratification and planes of cleavage, but could not find any explanation. Sedgwick (1822 and 1835) suggested that the cleavage of rocks might be due to the action of polar forces along a definite direction, causing orientation of crystals in that direction. J. Phillips, in 1843, at a meeting of the British Association, pointed out the deformation of fossils in cleaved rocks, and thought cleavage was the result of a slow creep of the minute rock particles in a definite direction. An important observation was made by the brothers Rogers, who showed, in 1837, that the cleavage-planes in the Alleghany mountains extended parallel with the main axis of upheaval of this mountain system, but in explanation they accepted Sedgwick's theory of polar attraction.

Almost simultaneously, the action of lateral pressure was suggested by two observers: in 1846 by Baur, an overseer of mines in Eschweiler, who explained the cleavage of the greywackes in the Rhine Province by this means; and in 1847 by D. Sharpe. Sorby in 1853 made pressure experiments, and succeeded in reproducing cleavage artificially in different kinds of rock. His results were supported by the later experiments of Tyndall (1856) and Daubrée (1861).

When, therefore, Lossen from his actual field observations drew the important conclusion that crust disturbance had been the chief agent in effecting cleavage metamorphism, he was in a position to refer to the confirmatory evidence in favour of

dynamic action which had been already afforded by experimental attempts.

In 1887, a few months after Lossen's work on the Taunus had appeared, C. W. von Gümbel published his *Geognostic Description of the Eastern Bavarian Frontier Mountains.* In it he tried to demonstrate that gneiss and crystalline schist represented the oldest sediment which had separated out under peculiar conditions from a magma impregnated with superheated water. Gümbel regarded the cleavage of gneiss and the crystalline schists in the Bavarian forest not as a subsequent development, but as true stratification, and compared the succession of the gneiss and schist series, as well as the gradual transitions and frequent alternations of the different varieties, with the characteristic appearances observed in a series of sedimentary deposits. He described the occurrence of certain massive rocks, such as granite, syenite, diorite, sometimes in regular alternation with the gneiss and schist, sometimes as intrusive bosses and dykes. Judging from the resemblance in the mineralogical composition of all these massive rocks, Gümbel argued that the rock-material must in all cases have had a similar origin, and concluded that there was an underground magma constituted like the primitive earth, and from which either sedimentary schist and gneiss, or granitic bosses and layers, could develop.

Justus Roth, who was one of the founders of the German Geological Society, was an ardent supporter of the view that all gneissose and schistose rocks represented the products of the first consolidation of the crust. In his work on *General and Chemical Geology*, published in 1890, two years before his death, Roth gave an unfavourable criticism of all theories which advocated subsequent rock-deformation and metamorphism. He contended that the compact structure of gneisses and schists, the absence of any amorphous or glassy ground-mass, together with the mineralogical composition, are features which indicate a plutonic, aquo-igneous origin. Their bent and cleaved character was attributed by him to the contraction of the earth and the consequent strains acting during the formation of the series.

Many geologists were, however, finding in the field ample confirmation of Lossen's explanation of the mechanical deformation of rocks. The well-known writings of Heim and Baltzer on the Swiss Alps, of Renard on the rocks of the

Ardennes, and of Lapworth on the north-west Highlands, revealed many new and highly interesting subjects of research in connection with dynamo-metamorphism.

Johann Lehmann, in the work mentioned above (p. 355), accepted the views of Lossen, and demonstrated the effects of "dislocation metamorphism" from a large number of excellent illustrations of microscopic rock-sections. According to Lehmann, the metamorphic rocks may be arranged in two groups. One comprises the various modifications of gneiss, granulite, felsite, and hornblendic schist which have originated as rock-material consolidated from molten magma, and have received their characteristic foliate structure from the action of pressures before solidification had been completed. He advocated the plutonic origin of this group upon the assumption that there is in the crust a corresponding rock-magma, the source of the deep-seated eruptive rocks, granite, syenite, diorite, gabbro, and that these rocks are connected with the gneiss group by a complete series of transitional modifications.

The other group comprises the remaining crystalline schists, gneissic schist, micaceous schist, chloritic schist, talcose schist, phyllites, etc. These have been produced by "dislocation metamorphism" carried out in very high degrees. In the case of gneissic schist the original rock-material, while undergoing the processes of metamorphism, has been invaded by, or impregnated with, granitic injections, but the series of typical schists have been metamorphosed without any injection of foreign magma. The original character of the rock-material is, according to Lehmann, not always demonstrable, but he thinks it abundantly evident that the metamorphic series is intimately associated in the field both with fragmental or clastic deposits and with rocks of igneous origin. Lehmann insisted that it was erroneous to attribute the metamorphic schists to a definite, pre-Cambrian geological epoch; it was in his opinion far more probable that they belonged to the different epochs during which extensive mountain-movements had been in progress. Professor Barrois in 1884 likewise showed that the schists and gneisses in Brittany, which had been regarded as pre-Cambrian, really represented metamorphosed sedimentary deposits belonging to various Palæozoic epochs.

The involved stratigraphical problem presented by the

extensive district of regional metamorphism in the north-west of Scotland had meantime been brilliantly elucidated by Professor Lapworth. Messrs. Peach and Horne, together with other members of the Geological Survey, were continuing the work of mapping and research in the new light that had been thrown on the problem by Lapworth's demonstration of the great crust-movements of overthrust, and the associated metamorphism of portions of the Cambro-Silurian deposits. It was securely determined in that district of regional metamorphism that there was fundamental gneiss at the base of the whole sedimentary succession, and also metamorphic gneiss representing sedimentary rocks of the oldest Palæozoic epochs which had been locally altered during the gigantic crust-movements. The altered and unaltered deposits dovetailed into one another with complicated stratigraphical relations.

The conclusive results of the work done in the north-west Highlands of Scotland were of the highest importance for the general questions in dispute regarding the causes and processes of metamorphism. In more recent years, Mr. Barrow has shown the presence of eruptive bosses of gneiss as well as of granite, and has traced numerous veins of pegmatite passing from these bosses into the group of crystalline schists.

The last fifteen years of the nineteenth century witnessed very great advances in our knowledge of rock-deformation and metamorphism. It has been found that there is no geological epoch whose sedimentary deposits have been wholly safeguarded from metamorphic changes, and as this broad fact has come to be realised, it has proved most unsettling and has necessitated a revision of the stratigraphy of many districts in the light of the new possibilities. The newer researches scarcely recognise any theory; they are directed rather to the empirical method of obtaining all possible information regarding microscopic and field evidences of the passage from metamorphic to igneous rocks, and from metamorphic to sedimentary rocks. The present views held by the leading German petrographers, Rosenbusch and Zirkel, may be in conclusion shortly indicated, as they will give a fair representation of the existing progressive and conservative tendencies regarding the difficult questions of pressure-metamorphism.

Rosenbusch has strongly advocated the origin of the crystalline schists through dynamo-metamorphic agencies. In a

paper written in 1889 he does not confine the metamorphic action of mountain-movements to sedimentary formations, but in common with Lehmann he regards gneiss, hornblendic schist, and other crystalline schists as eruptive rocks (granite, syenite, diorite) in which planes of schistosity have been developed under the influences of pressure and stretching. Rosenbusch does not believe it possible that the fundamental gneisses and schists could have originated as chemical precipitates from a primæval ocean, or any primæval mixture of rock-material and superheated water. As he further points out, the idea has been exploded that schistosity is a feature peculiar to Archæan rocks, it may indeed be possessed by young-Tertiary rocks. From the general distribution and stratigraphical position of the "fundamental" series, Rosenbusch concludes that it represents in its deeper horizons the first consolidated crust. He thinks the agreement in the mineralogical composition, as well as the interleaving of the Archæan gneisses and schists with the oldest eruptive rocks, would seem to indicate that the Archæan foliated rocks have at least in part originated from the same magma as deep-seated plutonic rocks. But whereas in the case of the granite-grained bosses of rock there is internal evidence that the minerals had separated from the magma in a definite order according to chemical laws, this is quite lacking in the gneissose and schistose rocks, which rather indicate that consolidation had been controlled by mechanical pressure.

In chemical respects the crystalline schists agree sometimes with massive eruptive rocks, sometimes with sedimentary rocks, and in all probability they have originated from various rocks, from deep-seated and eruptive masses, from intrusive and superficial eruptive flows, from eruptive tuffs, and from all kinds of stratified deposits. According to Rosenbusch, dynamo-metamorphism is the active principle that produces the banded and finely foliated forms of rock-structure.

In his *Elements of Petrology* (1898) Rosenbusch defines the crystalline schists as "eruptive or sedimentary rocks which have been geologically transformed through the essential co-operation of geo-dynamic phenomena." He distinguishes the "fundamental" series as an independent primæval formation, and describes the younger schists as local facies of different rock-varieties and not confined to any geological epoch.

Credner and Zirkel take exception to these views in certain

points. They admit the conversion of certain granites to gneissoid rocks, but do not agree that dynamo-metamorphism has had any part in the origin of the true Archæan gneisses and schists. Credner finds it difficult to understand how such a uniform succession as is presented by the fundamental crystalline rocks in the ancient mountain-systems could have been the product of variable and accidental processes of crushing and permeation by water.

Zirkel draws attention to the fact that the typical fundamental rocks and even the younger schists in many districts show only very slight traces of mountain-pressure, and on the other hand sedimentary rocks have often suffered gigantic tectonic disturbances and pressures, and yet have not been much changed in their original constitution. The petrographical researches of Professor Salomon have during the last few years attracted considerable attention. Professor Salomon has investigated the contact phenomena associated with deep-seated eruptive rocks in the Alps, more especially in the Adamello group, and has shown that different kinds of rocks have throughout long distances been altered by contact metamorphism into crystalline schists. On the basis of his observations in the Adamello, in the Cima d'Asta, and Predazzo districts, and in other parts of the Alps, Salomon has inferred that the granite-grained bosses of the Tyrol Central Alps are not, as Broegger concluded, of Triassic age, but were intruded in the Tertiary epoch. The magmas solidified in the form of laccolites and batholites, and as the form of the intruded material frequently varied in its relation to the crystalline schists during its cooling and contraction, Professor Salomon thinks it possible that the latest Alpine upheaval may have been induced by such variations and the consequent disturbances of crust equilibrium.

Although the hypothesis of dynamo-metamorphism has now very numerous adherents, many questions regarding the origin of the fundamental and the younger schistose rocks have yet to be solved before the principles of metamorphism can be securely defined, and as the subject is still under discussion, it is not well suited for historical interpretation.

CHAPTER V.

PALÆONTOLOGY.

After William Smith, Alexandre Brongniart, and Cuvier had disclosed to geologists the significance that attached to fossils as organic relics characteristic of successive geological epochs, some of the most enlightened scientific men of the day shared the increased interest in the study of fossils, and, greatly to the advantage of this branch of research, directed their genius to the examination, identification, and classification of fossils in the light of comparison with the existing plant and animal world. Blumenbach, Cuvier, Lamarck, Schlotheim, and others applied the scientific methods of Zoology, Comparative Anatomy, and Botany to the investigation of the remains of fossil organisms. A knowledge of fossil remains was no longer viewed as the hobby of a few dilettantes, but at the chief seats of learning was elevated to the rank of an independent mental discipline in the scientific curriculum. The new science was given the name of "Palæontology" almost simultaneously by two eminent authors, Ducrotay de Blainville and Fischer von Waldheim (1834), and the name was rapidly adopted in France and England, although in Germany the older terms "Petrefaktenkunde" and "Petrefaktologie" held their place for many decades.

Two directions were from the first apparent in palæontological research—a stratigraphical and a biological. Stratigraphers wished from palæontology mainly confirmation regarding the true order or relative age of zones of rock deposits in the field. Biologists had, theoretically at least, the more genuine interest in fossil organisms as individual forms of life; for the biologist or student of existing life the supreme value of palæontology was the evidence it might bring towards the solution of the problems of the genesis and evolution of living forms, determination of species and genera, variation of types in its relation to climatic conditions, distribution of types in respect of

geographical provinces, and many other fascinating subjects for scientific thought and investigation.

The stratigraphical aspect of palæontology is, however, the chief care of the geologist. He has to unearth the fossils, note their environment, trace the particular fossiliferous bed of deposit in its farther extension, and observe whether the fossils are only of sporadic occurrence in that horizon of rock, or are distributed throughout wide areas; again, whether the fossils are less frequent at that horizon than at some other horizon a little above or a little below in the rock-succession, or if the fossils are so very abundant at that horizon as to represent leading fossil types, characteristic of that geological horizon or zone of rock.

Many writers on fossil organisms have treated them merely as a means of identifying the age of the rocks, and have neglected the biological features. More general interest is commanded by descriptions of complete faunas and floras belonging to a definite epoch in the geological history of the earth. Although monographs of this character are, in the first instance, of stratigraphical value, the data which they bring forward are of use in determining the development of organic creation.

The first attempt at a Chronological Succession of fossil organisms is to be found in H. G. Bronn's[1] *Lethæa Geognostica* (1835-38). This work is a masterpiece of scholarship; it sum-

[1] Heinrich Georg Bronn, born on the 3rd March 1800, at Ziegelhausen, near Heidelberg, the son of a forester, studied in Heidelberg, and became a university tutor there in 1821; in 1828 Professor of Zoology and Technology. Between 1824 and 1827 he travelled in Upper Italy and Southern France for the sake of palæontological and geological studies. From 1830-62 he was one of the co-editors of the *Jahrbuch für Mineralogie, Geognosie, und Paʼæontologie.* His chief works, the *Lethæa Geognostica*, the *Handbook of Natural History*, the *Investigation into the Developmental Laws of Organised Nature*, brought him the reputation of being the most distinguished palæontologist in Germany. His difficulty of hearing was a decided drawback to his teaching powers. Wissmann, Lommel, G. Schweinfurth, and Zittel are among his grateful scholars. Bronn died in 1862 in Heidelberg, from lung disease. The first volume of the *Lethæa Geognostica* appeared in 1835, and was so widely circulated that a second edition of it was called for before the publication of the second volume—the latter was published in 1838. A third edition in three volumes, and with 124 plates, was published between 1851 and 1856, with the co-operation of Ferdinand Roemer, who had undertaken the preparation of the Palæo-Lethæa or Carboniferous Period. A fourth edition was begun in 1876 by Roemer, and is at present being continued by Professor Frech.

marises all that was previously known about stratigraphy and palæontology. The most important fossil types of all the geological formations are shown on the forty-seven folio plates, and the text gives careful descriptions of the fossils and their occurrence.

The *Lethæa Geognostica* was followed in 1848-49 by an *Index Palæontologica*, in which Bronn was assisted by Goeppert and H. von Meyer. Both these works exerted a great influence on the development of palæontology, and were for several decades the chief books of reference for all the more comprehensive palæontological works. Several other large works were published in the early part of the nineteenth century; among others, the *Mineral Conchology of Great Britain*, by the Sowerbys, between 1812 and 1845 (*ante*, p. 131); the splendid series of plates, *Petrefacta Germaniæ*, by Goldfuss[1] and Count Münster; the *Paléontologie Française*, by Alcide d'Orbigny (1840-55). Goldfuss and Münster[2] intended to produce an illustrative work of all the invertebrate fossils occurring in Germany, but apparently found the scheme too extensive, and concluded the work after the sponges, corals, crinoids, echinids, and a part of the fossil mollusca had been accomplished. D'Orbigny also gave up his similar scheme of an exhaustive illustrated account of all the fossil Invertebrates in France; he brought to completion monographs of the Jurassic and Cretaceous Cephalopods, Gastropods, the Cretaceous Lamellibranchs, Brachiopods, and Bryozoa, and certain groups of the Cretaceous Echinids.

In the first volume of the *Elementary Course of Palæontology and Stratigraphical Geology* (1849), D'Orbigny gave a short systematic summary of fossil organisms. The *Prodrome of Palæontology* is a list of the fossil Mollusca, Sponges, and Foraminifera arranged according to the geological epochs, but the list is much less complete than Bronn's *Palæontological Index*.

[1] Georg August Goldfuss, born 1782 at Thurnau, near Bayreuth; studied in Erlangen, graduated there in 1804, in 1818 was made Professor of Zoology in Erlangen, but was soon after called to Bonn University as Professor of Zoology and Mineralogy; died 1848, in Bonn.

[2] Count George Münster, born 1776 of a Hanoverian family, held office as a Bavarian Chamberlain, and lived in Bayreuth, where he died in 1844. His famous collection of fossils was procured by the Bavarian State and removed to Munich, where it formed the nucleus of the present Palæontological Museum.

The Palæontographical Society was established in London in the year 1847 for the purpose of illustrating and describing the whole of the British Fossil Species. The work it has accomplished is most praiseworthy. Each year has seen the publication of a volume containing monographs by the first specialists. Among the contributors have been Richard Owen, H. Milne-Edwards, E. Forbes, T. Davidson, H. Woodward, Ray Lankester, Traquair, Nicholson, Lapworth, Hinde, and many others whose names have a world-wide repute in connection with their special researches of animal groups. The publications of the Palæontographical Society undoubtedly take the first place in the literature of fossils, although the monographs are confined to British fossils. A more universal character is presented by the volumes of the *Palæontographica*, a periodical which was commenced in 1846 by W. Dunker and H. von Meyer. For the last three decades the *Palæontographica* has been conducted by K. von Zittel, and now numbers forty-six volumes. Similar palæontographical journals have been instituted in Austria-Hungary, France, and Italy.

Some of the more important works which treat fossils rather from their biological than their stratigraphical standpoint are Buckland's *Mineralogy and Geology* (1836), G. A. Mantell's *Medals of Creation* (1844), and the excellent *Traité élémentaire de Paléontologie*, published by F. J. Pictet at Paris (1844-46). Buckland's widely-circulated book was translated into German by the elder Agassiz. In the short geological introduction, Buckland impresses upon the reader the confirmation given by the geological record to the words of Holy Writ; then follows an attractively written account of fossil organisms, in the course of which frequent reference is made to the modes of life of the various animal groups, and to the relations subsisting between the fossil and living representatives of organised existences.

Pictet[1] treated palæontology as an essential part of the studies

[1] François Jules Pictet, born on the 27th September 1809, scion of an aristocratic family in Geneva. He studied Law and Science at the Geneva Academy, and went in 1830 to Paris, where he associated much with Cuvier, Geoffroy Saint-Hilaire, Blainville, and Audouin. In 1833 he returned to Geneva, interested himself chiefly in entomology and Comparative Anatomy, and married Miss de la Rive, a grand-daughter of Necker de Saussure. In 1835, Pictet was appointed Professor of Zoology at the Academy, but retired in 1859, in order to devote himself wholly to his

of Zoology, Comparative Anatomy, and Botany. He confined himself in his treatise to fossil animals, and adhered to a strict systematic order throughout his work, constantly keeping in view the characteristics of the corresponding living forms. At the same time, the geological occurrence of the fossils is nowhere omitted. In his treatment of the Mollusca and Echinoderms, Pictet agrees as a rule with D'Orbigny's views; in classifying the Vertebrates he relies chiefly upon the works of Cuvier and Agassiz. Pictet's work was taken as a model for a number of text-books which rapidly made their appearance. *The Principles of Palæontology*, by H. B. Geinitz (1846), keeps closely to Pictet's order and treatment of the subject; C. G. Giebel's *Palæontology* (1852) is merely a short summary, his unfinished *Fauna of the Past* (1847-56) is a diligently compiled enumeration of all known Vertebrates, Cephalopods, and Arthropods. A large number of new observations and illustrations are contained in F. A. Quenstedt's well-known account of fossils, *Petrefaktenkunde* (Tübingen, 1852). The work had passed through three editions in 1885, and for more than three decades was the chief handbook of palæontology used by the German students. Quenstedt's larger work, *Petrefaktenkunde Deutschlands*, with two hundred and eighteen plates, was published at intervals between 1846 and 1878. As a collective book of reference on the Vertebrate fossils found in Germany, it is indispensable in palæontological libraries. Sir Richard Owen's *Palæontology* (1860) provides an excellent general survey of the Vertebrate animals, but the Invertebrates are insufficiently treated.

The systematic direction of palæontology was until 1860 under the influence of Cuvier's theory of the invariability of species. Lamarck's bold hypotheses regarding the transmutation and descent of organic forms remained almost neglected by palæontologists, although H. G. Bronn, Quenstedt, and a few others had no belief in the fixed invariability of species, nor in the sharp distinctions drawn between successive periods of creation supposed to have been separated from one another

palæontological labours, and the direction of the Natural History Museum. Between 1866 and 1868 he became Rector of the Geneva Academy, and was at the same time a member of the Council of Education for the Zürich Polytechnic School; he also took an active part in political life, was a member of the Grand Council of Geneva, and of the National Council in Bern. He died on the 15th March 1872.

by great earth-cataclysms. Otherwise palæontological research between 1820 and 1860 made remarkable advances. Innumerable new forms were brought to light by zealous stratigraphers during their field surveys; while the museums were rapidly extending their collections, and affording ready opportunities to the younger minds of assimilating the broad facts and tendencies of palæontological investigations.

Schlotheim had in 1804 laid the ground-work of a knowledge of fossil plants, and Count von Sternberg[1] worthily continued these pioneer labours. His chief work, *Attempt at a Geognostic Botanic Representation of the Flora of the Past* (1820-32), describes two hundred fossil species of plants, and is illustrated by sixty splendid folio plates. Sternberg tried to insert the fossil species into the botanical system of existing floras, applied names correspondingly to the fossil species, and discarded the old names under which the fossil forms had been known. He accomplished much for the proper botanical significance of fossil floras, and paved the way for a scientific treatment of palæophytology.

A year after the appearance of the first part of Sternberg's work, Adolphe Brongniart[2] began his celebrated studies in fossil plants.

Like Sternberg, Brongniart also consistently carried out the examination and description of fossil plants strictly on lines of comparison with living plant-forms, and he arrived at similar results. Brongniart had at his disposal much more extensive material of observation than his German contemporary. His first *Treatise on the Classification and Distribution of Fossil Plants* is therefore the most complete and most scientific summary of all the fossil plants known before the year of its publication, 1822. A large, richly illustrated work, whose contents were made known in a preliminary *Prodrome*, was intended to form a fuller supplement to the earlier treatise, but unfortunately was never completed, and contains only the

[1] Kaspar Maria, Count von Sternberg, born 6th January 1761 at Serowitz (Bohemia), belonged to an old family, was president of the Bohemian National Museum, to which he bequeathed his library and collections; died 20th December 1838.

[2] Adolphe Théodore Brongniart, born 1801 in Paris, the son of the famous geologist, Alexandre Brongniart, studied medicine, but occupied himself chiefly with botany; was in 1833 appointed Professor of Botany at the Botanical Garden, in 1852 General Inspector of the University of France; died on the 19th February 1876, in Paris.

monographic description of a large part of the Cryptogams. Nevertheless, the unfinished work created a model of the best methods of palæophytological investigation.

Although an adherent of Cuvier's theory, Brongniart pointed out the gradual development of the floras in successive geological periods, and thought that the atmosphere, which had been in the earliest epochs warm and moist and supersaturated with carbonic acid gas, became purer and colder in course of time, and less suitable for the lavish development of vascular cryptogams. According to Brongniart, plant-life began on small islands in the primæval ocean; these islands afterwards united to continents, and the vegetation that spread over them always progressed towards more perfect types, and approached more nearly to the flora of the present epoch. He thought that the great changes in the floras and faunas of past ages had been effected contemporaneously by stupendous revolutions.

Peculiar results were obtained by J. Lindley and W. Hutton in their study of the fossil flora of Great Britain. Their unfinished work, consisting of three octavo volumes, was published between 1831 and 1837, and contains good descriptions and illustrations of most of the Carboniferous types. Both authors contest the existence of tree-ferns in the Carboniferous formation, doubt the relationship of the Calamites to the Equisetaceæ, and are of opinion that the Carboniferous flora included not only Conifers, but Cacti, Euphorbias, and other dicotyledons. They altogether deny a progressive development of the fossil floras.

Brongniart and his predecessors had identified the fossil forms exclusively from microscopic features: the finer structures came little into consideration. A new field of research was opened by several papers which gave an account of the microscopic structure of wood. One of the earliest was an essay by Sprengel (1828) on the silicified stems of trees (Psaronites). This was followed in 1831 by Witham's treatise on the structure of fossil and recent woods, and in 1832 by Cotta's richly illustrated work on the tree-ferns (various species of Psaronius) from the Red Underlyer or Lower Dyassic rocks of Saxony. An important work was published by August Corda between the years 1838 and 1842 on the comparative structure of fossil and recent stems. The illustrations of this work were admirably drawn by the author himself. The memoir in 1839

by Brongniart on the structure of Lepidodendron, Sigillaria, and Stigmaria is still treasured as a model of accurate methods of observation. His chronological summary of the periods of vegetation, and of the different floras according to their successive appearance on the face of the earth, is the first and most complete compilation of the fossil floras.

The numerous and valuable phytological works of H. R. Goeppert[1] extend over half a century, from 1834 to 1884. No other scientific man has been such a prolific writer on fossil plants, and there is scarcely any domain in fossil botany which has not come under Goeppert's special investigations. His monographs on the genera of fossil plants (1841-46), on the Tertiary floras of Silesia and Java, on fossil ferns (1836), and conifers (1850), as well as his excellent researches on the microscopic structure of fossil woods, coal and brown-coal, are among the best contributions that have been made to the knowledge of fossil vegetations.

In comparison with the flora of the older geological periods that of the Tertiary period was for a long time little investigated, but about the middle of the nineteenth century several works were devoted to this period. Franz Unger, Professor of Botany and Zoology in Graz, published between 1841 and 1847 the *Chloris Protogæa*, in which more than one hundred and twenty new species of Tertiary plants are described, illustrated, and classified under genera still existing.

In a second work on the flora of Sotzka, a great number of fossil Tertiary plants are represented on forty-seven folio plates, and the *Sylloge plantarum fossilium* (1860-66) contains descriptions and illustrations of three hundred and twenty-seven Tertiary species. The *Synopsis* of fossil plants (1845), of which a second edition appeared in 1855, provides a summary of the whole of phyto-palæontological material, and it was accompanied by the well-known series of coloured plates which Unger designed to convey an impression of the characteristic appearance presented by the successive floras in the world's history.

Alexander Braun (1845) made a special study of the remains of Tertiary plants found near Oeningen in Switzerland. The

[1] Heinrich Robert Goeppert, born 1800, at Sprottau in Lower Silesia, Doctor of Medicine, was originally a pharmaceutical chemist; in 1827 University Tutor, in 1831 Professor of Botany in Breslau; died 18th May 1884.

Zürich botanist, Oswald Heer,[1] has made his name famous by the admirable comparative researches which he carried out on the flora of Oeningen and other North Alpine localities. His first palæontological works reach as far back as 1847. His masterpiece appeared between 1855 and 1859, the *Tertiary Flora of Switzerland*, in two volumes, wherein no less than nine hundred species, for the most part new species, are described; one hundred and fifty-five plates illustrated the work.

His scholarly mind and wide knowledge of his subject enabled Heer to reconstruct in the ablest manner the different floras of the Tertiary epoch, to compare them with those of other Tertiary districts and of the present, and to discover by this means what had been the temperature and other climatic conditions during the growth of the successive Tertiary floras. The results of these important researches were afterwards published in the form of a popular scientific work, *The Primeval World of Switzerland* (1864), and roused great interest in a wide circle of readers. Another fundamental work by O. Heer treats the fossil flora of the Arctic regions. It consists of several independent treatises written in different languages; the whole work comprises seven quarto volumes, which were published between 1869 and 1884. The *Flora Arctica* forms not only an important contribution to the systematic knowledge of fossil floras, but is a work of the highest geological value on account of its inferences regarding the earlier climates of Arctic regions.

Heer advocates the view of a gradual approach of fossil floras to living creation, and a progressive differentiation and perfecting of all organised forms. He thinks the innate tendency of the organic world towards higher evolution was implanted in it by the Creator, and that evolution takes place in accordance with immutable laws. In his opinion, the variations of species and genera were not accomplished, as Darwin supposes, by means of slow modifications in the

[1] Oswald Heer, born 31st August 1809, at Niederutzwyl in Canton St. Gallen, the son of the Protestant pastor, studied Theology in Halle, and graduated, but in 1834 accepted a university tutorship at Zürich University; in 1852 was appointed Professor in the same University, and afterwards held also a Professorship in the Polytechnic Academy of Zürich. In 1852 he spent eight months in Madeira on account of lung weakness; in 1870 the old weakness broke out afresh, and on 27th September 1883 he died in Zürich.

course of countless generations, but at definite periods of creation, by means of a more or less complete re-modelling of the previously existing species in the plant and animal kingdoms.

The numerous, and in some cases beautifully illustrated, works of Abramo Massalongo (between 1850 and 1861) elucidate the Tertiary floras of upper and middle Italy. Another voluminous writer on Tertiary floras was Baron von Ettingshausen.[1] His first works discuss the Tertiary plants of the Vienna basin and the fossil Proteaceæ.

A method of securing a natural impression of leaves was about this time discovered in the Government Printing Office at Vienna, and Ettingshausen immediately had the method adapted to facilitate scientific researches of recent and fossil types of venation. In a memoir published in 1854, Ettingshausen showed the importance of leaf-venation for the systematic identification of isolated fossil leaves, and suggested a special terminology for the nervation of leaves. His large work is a handsomely-prepared account of Austrian plants in six volumes, *Physiotypia Plantarum Austriăcarum*, illustrated by natural impressions of the leaves. Pokorny collaborated with Ettingshausen in the preparation of this work, which was exhibited at the Paris Exhibition in the year 1867. Several independent monographs by Ettingshausen succeeded this work, and methods which he initiated have added very greatly to the security with which fossil leaves may be identified. Ettingshausen followed Heer in constantly making a comparison between recent and fossil forms, but, unlike Heer, he was an enthusiastic believer in the Darwinian theory of descent.

Meanwhile the knowledge of Carboniferous floras was being from time to time enriched. W. C. Williamson contributed several works (1851-68) on the Carboniferous flora of Great Britain; that of North America was being carefully examined by Sir William Dawson and Leo Lesquereux.

The first complete enumeration of palæophytological material

[1] Constantin Freiherr von Ettingshausen, born 1862 in Vienna, the son of the physicist, Andreas von Ettingshausen, studied in Kremsmünster and Vienna; worked as a voluntary assistant on the Imperial Geological Survey; in 1854 was chosen Professor at the Emperor Joseph Academy, and in 1871 Professor of Botany at Graz University; he died at Graz in 1897.

is found in the *Traité de Paléontologie végétale* (Paris, 1869-74), by Philipp Schimper, who was Director of the Museum in Strasburg, and a Professor in the University. Schimper handled the material essentially from a botanical standpoint, but was also an admirable exponent of the geological relations and significance of fossil plants.

August Schenk, for a long time (1868-91) Professor of Botany in Leipzig, exerted a very great influence on the advance of palæophytology in Germany. His detailed works were devoted to an investigation of the flora of the French Keuper, and more especially to the plant forms from the passage-beds between the Keuper and Lias. These appeared before 1868, while Schenk was still Professor of Botany in Würzburg. After his removal to Leipzig he came more into touch with Berlin influences, and he undertook the investigation of the large collection of fossil floras which had been brought from China by Baron von Richthofen and Count Széchenyi. Other materials examined by him were the silicified woods from the Nubian sandstones, fossil wood from Cairo, the plant remains from the Muschelkalk of Recoaro and from the Weald formation of England.

While all these were of the nature of special researches, a work of more general interest is Schenk's systematic treatment of the fossil plants in Zittel's *Handbook of Palæontology*. After the death of Schimper, who had only completed the cryptogams and cycads, Schenk undertook in 1881 the continuation of this work. By means of the critical method which he carried out uniformly throughout his classification of flowering plants in Zittel's handbook, and from which the works of the highest authorities, such as Unger, Heer, Von Ettingshausen, and Saporta, were not spared, Schenk practically initiated a reform in palæophytology. He showed how many of the fossil genera and species had been based on insufficient grounds of distinction, and how often miserably preserved fossil remains, whose identification was impossible, had been used for the erection of new genera or made the basis of some wonderful new hypothesis. Many of the special papers on fossil plants had been contributed by authors with insufficient botanical training, and were in consequence an untrustworthy foundation for any inductive reasoning regarding the past periods of vegetation and their climatic conditions.

Schenk was also very dubious about the value of Ettings-

hausen's application of leaf-nervation as a means of identifying fossil leaves, since the course of the leading bundles sometimes showed the greatest variability within smaller and larger groups, sometimes on the contrary showed scarcely any differences. The shapes of the leaves could, in his opinion, at the most be used only as a specific feature of distinction. To these inherent difficulties in systematic botany was added the fact that in the case of the fossil types it was quite exceptional to find leaves, flowers, and fruits embedded in the same localities in such a way as to demonstrate their original association with one another; and the want of caution displayed by many inquirers had created a mass of palæophytological literature which for scientific purposes was little more than useless ballast to be discarded.

Schenk fearlessly and patiently carried out the task of sifting the valuable results from the worthless, and by his precise and comprehensive knowledge of living forms he brought the scattered information regarding extinct forms into line with the most recent aspects of botanical science; his classificatory treatment of fossil floras is now adopted by the best authorities.

Schenk was a warm supporter of Darwin's theory of descent. His remarks on the genealogical relationships of the different fossil groups of plants and the modifications and variations of the ancient floras are of unusual interest. No less suggestive are his inferences regarding the climates of former ages and the general character of the vegetation. Schenk's views on such subjects frequently differ from those of Ettingshausen and Heer.

The Marquis of Saporta (1823-95), the head of a noble family, devoted all his leisure to the study of botany, and in 1860 began to interest himself especially in fossil plants. His writings are among the most valuable descriptions that have been given of fossil floras. They deal largely with the rich Tertiary floras of Southern France. He described the famous flora in the gypsum beds of Aix, in the Lower Eocene travertine deposits of Sezanne (1865), in the marls of Gelinden (1873), and in the Pliocene deposits of Meximieux (1876). Saporta was also the author of several successful popular works,[1] which

[1] The most widely circulated of Saporta's books are *The World of Plants before the Appearance of Man* (Paris, 1881 and 1885) and *The Palæontological Origin of Trees* (Paris, 1888).

elucidate the developmental phases of the floras of past time in the sense of the theory of evolution.

In his *Cours de la Botanique fossile* (Paris, 1881-85), M. B. Renault describes the fossil cycads, cordaites, sigillarias, lepidodendrons, stigmarias, ferns, and conifers. His classification adheres closely to the systematic arrangement of living plants. The same plant-groups, together with thallophytes, mosses, calamarias, and equisetes, are ably described in a German work which appeared about the same time, *Einleitung in die Palæophytologie*, by Count von Solms-Laubach (Leipzig, 1887).

Upon the whole, botanists have always taken a more important part than geologists in the advance of palæophytology, and in recent years the purely botanical treatment has become even more predominant. The severe strictures passed by Schenk on the uncritical palæontological papers that appeared so numerously in the middle of the last century have had their influence; now the author of a paper on any department of palæophytology is expected to have a sound knowledge of systematic botany.

It cannot be said that palæozoology has yet arrived at this desirable standpoint. Just as palæophytology has come to be regarded and treated scientifically as a branch of botany in the only true and wide sense, so should palæontology be regarded as a branch of zoology in its wide sense. But while the greatest scientific successes have been achieved by those research students who have treated their particular subject from this wider aspect, we find in the universities that palæontology is often relegated to the care of a geological specialist. Cuvier and Lamarck in France, and Richard Owen, Wallace, Huxley, Ray Lankester, Alleyne Nicholson have been brilliant exponents in Great Britain of the higher and wider scope of zoology. But comparatively few individuals have such a thorough grasp of zoological and geological knowledge as to enable them to treat palæontological researches worthily, and there has accumulated a dead weight of stratigraphical-palæontological literature wherein the fossil remains of animals are named and pigeon-holed solely as an additional ticket of the age of a rock-deposit, with a wilful disregard of the much more difficult problem of their relationships in the long chain of existence.

The terminology which has been introduced in the innumer-

able monographs of special fossil faunas in the majority of cases makes only the slenderest pretext of any connection with recent systematic zoology; if there is a difficulty, then stratigraphical arguments are made the basis of a solution. Zoological students are, as a rule, too actively engaged and keenly interested in building up new observations to attempt to spell through the arbitrary palæontological conclusions arrived at by many stratigraphers, or to revise their labours from a zoological point of view.

Until the sixth decade of the nineteenth century the exact description of genera and species received the chief attention in the literature both of zoology and stratigraphical palæontology. The individual faunas and floras of the past time were regarded by the adherents of the Catastrophal Theory as creations quite distinct from one another, whose order of succession and whose mutual relations it was the first duty of stratigraphy and palæontology to determine. In a prize essay of the Paris Academy, entitled "Investigations of the developmental laws of the organic world during the period of formation of our Earth's Surface" (Stuttgart, 1858), H. G. Bronn has supplied a valuable compendium of all the known palæontological material and the distribution of the fossils in the different strata.

In this work Bronn criticises unfavourably the theories of creation and development advanced by Lamarck, Geoffroy Saint-Hilaire, Oken, Grant, and others. He admits that modifications of organic forms may produce racial distinctions, but regards as fallacious, or at least wholly hypothetical, the *generatio æquivoca*, the gradual modification of species, the descent of all younger forms from older, as well as the evolution of more highly-perfected organisms from those on a lower platform of organisation. He assumes a creative force which not only brought forth the first organisms, but had continued during subsequent geological epochs to the present age, and had worked independently of chance circumstances and according to a definite plan. The unity of this plan was the basis of the apparent relationships between the types of successive creations; as certain types became extinct, others were created of similar but more perfect design to replace the gap in the organic world. Thus, by repeated substitutions, as Sedgwick, Hugh Miller, Brongniart, and Agassiz had already advocated, Bronn tries to explain the universal tendency in animate

creation towards the improvement of the type. Bronn recognises the frequency of so-called "mixed forms" uniting in themselves features which subsequently are distributed and specialised in different related genera or families, but he takes such forms to be incontrovertible evidence of the law of the introduction of improved forms.

As far back as 1849, L. Agassiz had distinguished progressive, prophetic, synthetic, and embryonic types among fossil organisms, and had attributed great importance to the prophetic and embryonic types as fore-runners and signs of coming changes in the organised relations. A similar conception was afterwards conveyed by Richard Owen in his definition of "plan forms" or "archetypes."

Both Agassiz and Bronn gave particular attention to the grades of differentiation and complexity, and to the systematic rank of an animal type, and enunciated fundamental principles of animal organisation. In 1854, Edward Forbes for the first time in literature pointed out the significance of degeneration, or retrogression of types, as shown in certain groups of animals.

According to Bronn, two fundamental principles have guided the whole succession of organisms from the oldest geological period to the present time: first, an extensive and intensive productive force continually increasing in power; and second, the nature and the variations of the external conditions. With remarkable skill and ingenuity, Bronn elucidates the circumstances and events upon which the activity of the productive force is dependent, as well as the varying conditions of the atmosphere, the climate, the distribution of land and water, the configuration of the successive land surfaces in the past ages, and the influence of the varying conditions on the animate creation. He infers from these considerations the law of *terripetal development*. From a primæval ocean rose cliffs, islands, and continents; the fauna of a universal ocean was succeeded by the first settlement of land animals and plants; as the islands and continents increased in size, and denudation altered their surfaces, new conditions of existence were provided for terrestrial and fresh-water inhabitants, and more complex correlations and differentiations of parts were rendered possible. The faunas and floras of the older geological periods bore a tropical impress: the temperature cooled very slowly, and as the conditions approached more nearly to those of the present age, the strange-looking orders, families,

genera, and species of the earlier ages gradually became extinct and were replaced by those of to-day.

But whereas Cuvier, Agassiz, D'Orbigny, and other supporters of the Catastrophal Theory had supposed the faunas and floras of any one geological period to be sharply defined from those of the foregoing and succeeding ages, and in fact to have no species in common, Bronn insisted that a smaller or larger number of genera and species passed from one age to the next, and have been in a measure *connecting intermediate links*. The creation of new types and the extinction of old types had not been confined to a few "days" or "periods" of creation associated with great earth catastrophes, but had been *continually and quietly going on* as a consequence of the changes in the external conditions of existence which had been likewise continuously in progress during the whole geological history of the earth. At the same time Bronn allowed that certain surface changes had been the cause of more far-reaching variations of form than others. The period of existence that had been assigned to the fossil species was extremely unequal; as a rule, however, it had been very long. The limits of the geological horizons, formations, etc., are neither in palæontological nor in geographical or lithological respect absolutely sharp, but are frequently more or less indefinable.

The able arguments of Bronn opened up a series of questions which until his time had either been entirely neglected by palæontologists, or had never benefited by a frank and lucid expression of their difficulties. Bronn's teaching was in close harmony with Charles Lyell's doctrine of the uniformitarian development of the earth; more especially Bronn's insistence upon the continuity in the processes of change, and his scientific demonstration of transitional species and genera bridging the supposed gaps in the palæontological and stratigraphical succession provided a stepping-stone for the acceptance of Darwin's grander principles. When, in the year 1859, Darwin's epochal work *On the Origin of Species by means of Natural Selection* appeared, it was Bronn who was one of the first in Germany to recognise it as the outcome of an extraordinary genius, and he immediately translated the work into the German language.

The publication, in 1866, of Ernst Haeckel's work on *General Morphology* was the first practical application of

Darwin's theory to zoological classification, and it exerted a widespread influence both in extending the knowledge of Darwin's leading principles and in demonstrating the great superiority of a scheme of classification based upon these principles over the many artificial schemes which had been previously proposed on the basis of recurrent earth catastrophes, or on that of repeated exhibitions of the creative force and the working of inscrutable laws.

A decade after the publication of the *Origin of Species*, Darwin's theory of descent was almost universally accepted as the most natural basis of classification in all the domains of the science of animal organisms. Darwin's conception of the origin of species could not fail to enhance the interest of palæontology. That study was realised to be no longer merely descriptive and comparative, or the means of bringing useful material to the sciences of botany and zoology, but a branch of knowledge to be studied for its own intrinsic interest.

The greatest likelihood of solving some of the obscure problems of the origin and extinction of species lay with the palæontologist, since the rich material at his command, extending through many successive ages, comprised the record of the incoming and outgoing of countless types of life. The origin, geological development, gradual modification, differentiation, improvement or degeneration of the individual groups of the animal and plant kingdom, the genealogical relations of the primæval and recent organisms, the phylogeny of the plant and animal world, the relations between the developmental history (ontogeny) of the single individual, and the history of descent (phylogeny) of the family, order, and class to which the individual belongs, are questions which can be answered either exclusively by palæontology or only with its assistance.

With Darwin begins the modern period of palæontological research. Numerous and important evidences were brought forward in favour of the doctrine of descent. The continuous series of forms, which can be followed through several stratigraphical horizons and formations with greater and less variations, the occurrence of mixed and embryonic types, the parallels of ontogeny with the chronological succession of related fossil forms (biogenetic principle of Haeckel), the similarity in the general impress of the fossil floras and faunas next each other in age, the agreement in the geographical

distribution of the existing organisms and their fossil ancestors, as well as many other facts, are only comprehensible on the assumption of the doctrine of transmutation.

Palæontology has taken an active part since 1870 in the establishment of the theory of descent, and at the present day phylogenetic problems are regarded as one of the chief charms in palæontological research. The character of palæontological literature has been correspondingly modified; the purely stratigraphical treatment of palæontological results has been held more and more distinct from the biological-systematic treatment, and the latter places the genealogical direction of research more and more in the foreground. The literature has been so extensively increased, and has been contributed in so many different languages, and often circulated in so few copies, that very great difficulties stand in the way of obtaining a complete general survey of its results. The older text-books of Bronn, D'Orbigny, Geinitz, Quenstedt, Giebel, Nicholson, and others were rapidly out of date, and were partially designed only to meet the requirements of beginners.

The *Handbuch der Palæontologie* of Karl A. von Zittel, the botanical part of which was written by W. Schimper and A. Schenk, endeavours to provide a general survey of palæontological subject-matter in harmony with the modern standpoint of zoology. The original intention of the author was to comprise Palæozoology in one volume, but as the work proceeded it extended to four thick volumes, and the completion of the work occupied seventeen years (1876-93). The chapter on fossil insects was contributed by S. Scudder. Throughout the entire work a primary object has been to point out the close relationships between palæontology and the other branches of biological science (Zoology, Comparative Anatomy, Botany, Embryology), and to make application to palæontology of the data acquired by those sciences. The subject-matter is therefore arranged in strict systematical order, and the enumeration of each particular group of forms is preceded by an introduction elucidating the main features of the organisation. The histological structures are described in much fuller detail than in any of the former text-books of Palæontology. In the special systematic portion, all well-founded genera are accepted and described, the doubtful genera are eliminated or only briefly mentioned. The

systematic account of each larger group of forms is followed by a brief sketch of the geological distribution and the phylogeny of the foregoing forms. Importance is given to the data which afford evidence of the genetic connection of the members of individual branches, classes, orders, and families; but the representation is kept free from bias towards one direction of thought or another. Where palæontology can bring forward no evidences in favour of the doctrine of evolution, or where considerable gaps occur in the palæontological sequence and seem to speak rather for the opposite views, the authors have consistently endeavoured to set forth the actual facts with full impartiality.

Zittel's *Handbook* has served as a model for nearly all the more recently published smaller text-books, such as those of Hoernes (1884), Steinmann-Döderlein (1890), Bernard (1895), Zittel (1895), and Smith-Woodward (1898).

Two works of very great interest have been added to geological and palæontological science by Neumayr.[1] The one is his *Erdgeschichte*, and is full of original and suggestive conceptions; the other is his *Stämmen des Thierreichs*, which unfortunately remained unfinished. The published portion, which comprises the groups of the Protozoa, Cœlenterata, Echinodermata, and Molluscoida, introduces many new points of view, and will have a permanent value both for palæontology and zoology.

Probably the most influential disciple and exponent of the theory of descent was the great English zoologist, Thomas Huxley. Cope in America, Gaudry in France, and Haeckel in Germany are zoologists who have likewise been in the forefront of the new teaching.

Huxley's palæontological works, like those of Gaudry and Cope, are mostly devoted to the vertebrate animals, and are distinguished by his remarkable acuteness of observation and his genius for inductive combination. His determination of

[1] Melchior Neumayr, born in Munich on the 24th October 1845, the son of a high state official, studied in Munich and Heidelberg; after he graduated, he entered in 1868 the Imperial Geological Survey Department at Vienna, and contributed several special papers on the geology of various areas of Hungary, Transylvania, and North Tyrol; in 1872 became a University tutor in Heidelberg, but in 1873 was called to Vienna to be Professor of Palæontology, a chair which had been founded especially for him. In the midst of his labours, he died on the 29th January 1890, of heart disease.

the genealogy of the horse, his elucidation of the genetic relations of birds and reptiles, his memoir on Crossopterygia, are among the classical productions of palæontological and zoological science. The works of Gaudry deal with the genealogical relations of the different classes of animals and their descent from primæval ancestors, and are written so convincingly, and with such elegance of style, that they have roused an interest for palæontology in the widest circles. Scientific interest is chiefly concentrated upon his admirable contributions to the genealogies of the fossil Vertebrates. E. D. Cope,[1] together with Herbert Spencer, may be regarded as the head of the Neo-Lamarckian School, which has a strong foothold in North America. In opposition to Darwin, the gradual changes in the organic creation are not explained as the result of natural selection, but chiefly attributed to the influence of use and disuse of parts, and also to the influence of the external environment, such as the supply of nourishment, climatic conditions, mechanical agencies, etc. Upon these principles Cope has attempted to explain the *Kinetogenesis* or gradual evolution and modification of the skeletal structures and teeth of Vertebrates. More recent work by H. F. Osborn, carried out in accordance with Cope's conceptions, has attained a certain success.

Amidst the very large number of special memoirs and books which treat individual sub-divisions and groups of fossil animals, it is only possible here to single out those which have exerted a marked influence upon the progress of systematic palæozoology, or on the phylogenetic relations of fossil faunas.[2]

[1] Edward Drinker Cope, born 1840 in Philadelphia, belonged to an old and wealthy family; as a boy he was fond of travel, and at nineteen years of age he published a valuable zoological memoir on Batrachians. On the conclusion of his studies in Philadelphia, he made a journey to Europe in 1863 to become acquainted with the European museums. In 1864 he accepted the post of Professor of Comparative Anatomy at Haverford College, but he resigned it in 1867. From 1865 onward, Cope devoted his time chiefly to the study of fossil Vertebrates, and partly at his own expense, partly as a member of the Hayden and Wheeler Expeditions, he made exploring tours in search of material through Kansas, Colorado, Wyoming, New Mexico, and Texas, at the same time producing a large number of memoirs. In 1889 he was appointed Professor of Geology and Mineralogy at the Academy in Pennsylvania; he died on the 12th April 1897. His large collection of fossil Mammalia was secured by the American Museum in New York.

[2] The works mentioned in the following pages are fully cited in the references subjoined to Zittel's *Handbook*.

Protozoa.—The fossil remains of Protozoa are naturally confined to those classes or orders which are shell-producing during life. The most widely distributed fossil representatives of the Protozoa are the Foraminifera or Polythalamia (Reticularia, Carpenter), which enter largely into the composition of many marine limestones, and whose occurrence has been known for several centuries to natural historians. The earlier memoirs of Breyn (1732), Soldani (1780), Fichtel and Moll (1803), Lamarck (1804-7), Denys de Montfort (1808-10), wherein a considerable number of these small forms are described and figured, were followed by the more comprehensive investigations of Alcide d'Orbigny (1824). These for the first time made the attempt to introduce a systematic order and classification into this group of testaceous organisms, which were still almost universally regarded as mollusca, belonging to the group of cephalopods.

D'Orbigny distinguished two main groups among the Polythalamia, one of which (Siphonifera) contains the chambered shells of the true cephalopods, while the other (Foraminifera) embraces the shells characterised by the perforations in the dividing walls of the chambers. The Foraminifera are then sub-divided by D'Orbigny chiefly according to the external features of the shell, and the number and arrangement of the chambers.

A number of the species enumerated in the *Tableau Méthodique* have been made known far and wide by enlarged models, which were distributed to various academies in 1825 and 1826. D'Orbigny also contributed a monograph on the fossil Foraminifera in the Tertiary deposits of the Vienna basin.

The advance effected by Ehrenberg's microscopic examination of thin slices of Foraminifera has already been mentioned (p. 326). But although so accurate an observer, Ehrenberg formed fallacious views respecting the organisation of the group, and thought the Foraminifera might belong to the Bryozoa. Dujardin in 1835 contested many of Ehrenberg's conclusions, and demonstrated that the Foraminifera belonged to the Rhizopoda. Williamson, Reuss, and especially W. B. Carpenter, objected to the previous schemes of classification which had been formulated merely upon external features of the skeleton and habits of growth. The investigations of Williamson on the fine details of structure, and the famous work by Carpenter on the *Microscopic Structure and Classifica-*

tion of the Foraminifera, completely overthrew the older classifications and formed the basis of our present intimate knowledge of these exquisite little shells.

Carpenter divided the Reticularia into two sub-classes: Imperforata and Perforata, and sub-divided each of these sub-classes into several families distinguished according to the chemical composition and microscopic structure of the tests. The views held by Carpenter and his collaborators, Parker and Jones, regarding the confines of the genera and species, differed very considerably from those of D'Orbigny, as the English zoologists often comprised under the same generic title forms very different in their external appearance, on the plea that they were connected by intermediate types.

Reuss has published from 1839 onwards a large number of papers, mostly in the Transactions of the Vienna Academy, describing individual species of fossil Foraminifera from all geological formations. The works of Parker and Jones, extending from the year 1857, follow the same direction of special research. The classifications of Schwager and Brady introduced several modifications of Carpenter's scheme. Brady pointed out that the sub-classes Imperforata and Perforata could not be so sharply defined as had been done by Carpenter, for example the group Lituolidea, which Carpenter had ranked under the sub-class Imperforata, included also certain species which were finely perforate. This matter, along with other systematic difficulties, has been more recently discussed by Ray Lankester, in his descriptive and classificatory account of the Protozoa, published in the *Encyclopædia Britannica*. Brady's Report on the Foraminifera of the *Challenger* Expedition, and his monograph of the Foraminifera in the Carboniferous Limestones of Great Britain, are two of the finest productions in this domain of research.

In the French literature of the Foraminifera, the excellent monograph of the Nummulites by D'Archiac and Haime takes the highest place. Terquem and Berthelin even at the present time are wholly disciples of D'Orbigny. Meunier-Chalmas and Schlumberger have, on the other hand, placed great significance on microscopic researches of the shell-architecture, and have made many interesting observations on dimorphic forms of the initial chamber. In Italy, Michelotti, Seguenza, Silvestri, and more particularly Fornasini, have described the Foraminifera present in the younger Tertiary deposits.

SIR RICHARD OWEN.

From a Photo by] [*Elliott & Fry*, Baker St., W.

In addition to the Foraminifera, the Radiolarians with siliceous or chitinous tests represent another class of Protozoa which come under consideration in palæontological researches. The knowledge of the Radiolaria does not extend so far back as that of Foraminifera. The earliest accounts of these microscopically minute organisms were given by Tilesius (1806) and by Meyer (1834); but Ehrenberg was the first investigator who disclosed the wonderful variety and beauty of their siliceous skeletons. In a series of special monographs and magazine articles extended over a long period of years from 1838 to 1875, Ehrenberg described many hundred forms belonging to this group, which he had called Polycystina. His material had been collected from recent oozes on the ocean-floor, and from the Tertiary marls of Sicily, Zante, Oran, North America, and Barbadoes, the last-mentioned locality alone providing 278 species. But Ehrenberg had very obscure notions about the organisation of the Polycystina.

The living structure and the systematic position of this group were elucidated by Huxley in 1851. A fuller exposition of the zoological aspects was given in 1855 by Johann Müller, who suggested the term of Radiolaria as better suited for the group than Ehrenberg's name of Polycystina. The beautifully illustrated monograph of the Radiolaria by Ernst Haeckel erected a complete classificatory system for the Radiolaria, and won universal admiration for the artistic representations of the infinite diversity in the skeletal forms produced by these simple organisms.

Haeckel's works are chiefly devoted to recent Radiolaria, and at that time, in 1862, science was only cognisant of the occurrence of fossil Radiolaria in the Tertiary deposits. Zittel, in 1876, described some older forms from Upper Cretaceous strata, and between 1885 and 1892 D. Rüst carried out a long series of researches, preparing microscopic sections of siliceous rocks from all the geological formations; he succeeded in demonstrating the presence of numerous Radiolarian species from the Cambrian or oldest Palæozoic formation onwards to the present age.

Brief mention must be made of a controversy that arose regarding certain structures thought to represent the oldest known animal organism. In the year 1858 MacCulloch collected in the Laurentian gneiss of Canada curious aggregates of serpentine and calcite, arranged in irregular alternate

layers, the serpentine having rather a reticulated distribution in a ground-mass of calcite. Logan regarded such aggregates as altered masses of an originally organic growth, and in 1864 Sir William Dawson described these reticulate structures as the ramification of a Foraminiferal growth under the name of Eozoon Canadense. This view was supported by Carpenter in 1876, and was afterwards confirmed by Parker, Jones, Brady, Reuss, and other specialists, whereas King, Rowney, and Carter contended that the supposed Eozoon was not an organic structure, but had been produced by processes of mineralogical segregation. The controversy continued for many years, until Moebius, of Kiel University, published what is considered by most geologists a decisive paper in favour of the inorganic origin of the Eozoon structure. Moebius contended that the serpentine matter of the "Canal System" had been infiltrated into the calcite along fine vein-fissures disposed in the calcareous rock with exceptional regularity.

Sponges.—No group among the Invertebrates resisted scientific treatment so long as the fossil sponges. This is scarcely surprising, when it is remembered that zoologists were still in doubt in the early part of the nineteenth century whether the marine sponges belonged to the vegetable or animal kingdom. The pioneer investigations of Robert Grant (1825) first afforded a true conception of the organisation of these creatures; and after Grant, several English scientists—among others, Johnstone, Bowerbank, and Carter—made important advances towards securing a better grasp of the morphology and systematic relations of the group.

The backward state of zoological knowledge of living sponges made it almost impossible for palæontologists to attempt anything more than a description and illustration of the fossil sponges. The first volume (1826) of the *Petrefacta Germaniæ* of Goldfuss and Münster included seventy-five species of fossil sponges, which the authors distributed under eleven generic names; but the work of Goldfuss shows little advance on the works of earlier writers, Guettard, Parkinson, Mantell, and others. The works of Michelin (1840-47) and Blainville also yield merely descriptions of the external form, without any account of the finer structural features. These authors take the same standpoint as Goldfuss, in assuming that the fossil sponges are ancestral forms of the living ceratose sponges, in

which the horny fibres had been changed to stone by means of the processes of petrefaction. Similarly, the works of Geinitz, Klipstein, Pusch, Reuss, Quenstedt, and Roemer increase the knowledge of the endless diversity of form presented by sponges, but add little to a scientific comprehension of their structure.

A notable position in the older literature of sponges is taken by the two short memoirs of Toulmin Smith (1847-48), wherein the structure of the Ventriculites from the white chalk is fairly accurately represented. Owing, however, to the fact that the nearest allies among living sponges, the Hexactinellids, were unknown at the time of his investigations, Smith drew fallacious inferences regarding the nature and systematic position of these fossils. He compared them with Bryozoa.

In the year 1851, D'Orbigny devised a badly-arranged scheme of classification for fossil sponges, upon the basis solely of external features. He called all fossil sponges "Petrospongiæ," and contrasted them with recent sponges, ascribing to fossil sponges an originally stony skeleton composed of calcareous fibres. According to D'Orbigny, the petrospongiæ form a curious and extinct sub-division of the sponges. This erroneous conception of D'Orbigny's was shared by Fromentel, but the latter author, in differentiating genera and species, made use of differences in the canal system and in the kinds of pores and openings at the surface. Friedrich Roemer followed Fromentel's method, and he differentiated between sponges with fenestrated skeletal structure and sponges with a skeleton composed of "worm-shaped fibres." Pomel also made careful observations of the skeletal structures so far as those could be distinguished with the naked eye or by the aid of a hand-lens.

The deep-sea investigations of the last part of the nineteenth century initiated a new era in the investigation of sponges, recent and fossil. Wyville Thomson, the leader of the *Challenger* Expedition, was the first to point out the similarity in the structures of fossil ventriculites and living silicispongiæ. In 1870, Oscar Schmidt, by the method of etching Jurassic and Cretaceous specimens, demonstrated in fossil forms the presence of certain skeletal structures similar to those of existing hexactinellids and lithistids. Nevertheless the fossil sponges still presented an apparently distinct and well-defined group, until almost simultaneously Zittel and Sollas resolved to apply Nicol's method and prepare thin slices of the fossil

material for microscopic examination. In 1877, Sollas demonstrated, by his examination of several genera belonging to the English chalk, the identity of their structure with that of living hexactinellids, lithistids, and monactinellids. Zittel, in 1876, published his microscopic investigations embracing the whole of the fossil sponges, together with a monograph of the genus Cœloptychium. In this work, as well as in the studies published during the following year, it was fully demonstrated that all fossil sponges could be included in the scheme of classification erected for existing sponges. Zittel succeeded in showing that a large number of sponges referred to the Calcispongiæ by previous authors had been originally arenaceous, but the sandy material had been dissolved, and in its place calcareous substance had been laid down. This removed the greatest difficulty in the study of fossil representatives of the Silicispongiæ. Zittel also demonstrated the true calcareous structures of numerous fossil Calcispongiæ, whose existence had been called in question by E. Haeckel in his monograph of the Calcispongiæ (1872), and in spite of much contradiction at first, Zittel's evidence ultimately received general acceptance.

The application of the microscopic method, which had been used by Zittel and Sollas, was followed in almost all the later publications on fossil sponges, and the classification proposed by Zittel for recent and fossil sponges was confirmed in its main features and further improved by the zoological and anatomical investigations of O. Schmidt, F. E. Schulze, Carter, Vosmaer, Lendenfeld, and others.

The most distinguished students of fossil sponges at the present day are G. J. Hinde and Hermann Rauff. The former has published a monograph of the fossil sponges (1884) in the Natural History Collection of the British Museum, and is at present engaged on a monograph of the fossil forms of Great Britain, parts of which have appeared since 1887 in the publications of the Palæontographical Society. Rauff has produced in his *Palæospongiology* (1893) an exemplary representation of all the palæozoic forms of sponges.

Cœlenterates.—Up to the year 1825 there was great insecurity about the organisation of the organisms at present comprised under the group of the Cœlentera. The schemes of classification attempted by Lamouroux, Esper, Lamarck, and others are full of errors; the researches of Ehrenberg and

Milne-Edwards first revealed the anatomical structure of zoophyte organisms, and made it possible to differentiate them from a number of other forms with which they had been erroneously included in previous classificatory systems. Ehrenberg based his classification of coral zoophytes exclusively on the characters of recent corals, more especially on his examination of the Red Sea corals. The number of tentacles was, in his opinion, the leading feature of distinction; according to it he erected the main sub-divisions of his classification.

Fossil corals were described and figured in most of the larger palæontological works that appeared during the first half of the nineteenth century. The illustrative plates of Goldfuss (1826), Michelin (1841-47), Lonsdale and MacCoy display a large number of fossil species, but notwithstanding the advances that were being made in the knowledge of living corals, the systematic treatment of fossil corals in these works is as crude and antiquated as in the much earlier works of Guettard, Parkinson, and Schlotheim. The profound and exhaustive works of Milne-Edwards[1] and Haime revolutionised the study of corals. These scientists made a thorough investigation of the organisation of living polyps, and from that proceeded to examine group after group of the fossil corals, directing attention equally to the evidences afforded by the skeleton regarding the original form and structure of the fossil polyps, and to the phylogenetic indications given by the occurrence and distribution of the fossil faunas in the stratigraphical succession. The penetrating critical instinct and unbiassed judgment of the authors produced a work which is recognised to be one of the most skilful that has ever appeared in scientific literature. The classificatory system of Milne-Edwards and Haime is based upon the character of the septa and the mode of their increase in number, and with a few modifications, the system has remained until the present day.

Later works on fossil corals for the most part dealt with the coral faunas of particular localities or of a particular stratigraphical horizon. Of special value are the monographs of Reuss, Fromentel, De Koninck, Koby, Hall, Becker,

[1] Henri Milne-Edwards, born 1800 in Bruges, studied medicine in Paris, and was at first the Professor of Natural History in the Collège Henri IV., then in 1841 at the Museum. In the year 1862 he was appointed Professor of Zoology, and two years later Director of the Museum; died 1885 in Paris.

Milaschewitsch, D'Archiardi; and Duncan's book on British fossil corals has enjoyed a wide circulation. Quenstedt alone adheres both in his text-books and his *Palæontology of Germany* (vol. vii., 1889) to the old system of Ehrenberg, and continues to group the Bryozoa along with the corals.

A short but very important paper was published in 1869 by A. Kunth. This observer pointed out the fundamental difference in the method according to which new septa had developed in the Palæozoic group of the Rugosa, as compared with the order of intussusception of the septa in the younger corals; and he showed how with this difference was associated the bilateral symmetry of the Rugose corals on the one hand, and the radial symmetry of the younger corals. After the publication of Kunth's memoir, the Rugose corals, also known under the synonyms of "Tetracorallia" or "Pterocorallia," were treated as an independent group in the classification of corals, distinct from the younger group of "Hexacorallia," for which Milne-Edwards' and Haime's observations still held good. Kunth's work gave a new impulse to the study of the Rugose group of Palæozoic corals, and was followed by a number of special memoirs, those of Dybowski, Nicholson, Schlüter, Lindström, and Frech, among many others.

In 1872, Lacaze-Duthiers made known his valuable embryological investigations, which necessitated a new revision of the laws of septal symmetry enunciated by Milne-Edwards and Haime. The discoveries made by L. Agassiz and Moseley regarding the zoological relationship of Millepora and Heliopora entirely overthrew the group of Tabulata as it had been defined in the system of Milne-Edwards and Haime. And Dybowski, Roemer, Nicholson, and other leading authorities on Palæozoic corals then endeavoured by the most detailed investigations of the growth-relations, the organisation, and finer structure, to explain the remarkable diversity of forms comprised in this group.

The microscopic structure of the calcareous skeleton had been little taken into consideration by Milne-Edwards and Haime. In 1865, Kölliker first directed attention to it; in 1882, there followed almost simultaneously the works of Pratz and Koch, showing illustrations of microscopic sections, and a similar method was followed by Nicholson, Frech, Volz, Felix, Struve, and others. The most comprehensive investigation into the microscopic structure of the skeleton of living and

fossil corals has been contributed by Maria M. Ogilvie (1896). Upon the basis of her comparative microscopic researches, the authoress suggested certain classificatory reforms which appear to weaken very materially the strong distinctions previously drawn between the Tetracorallia and Hexacorallia, as well as between the Hexacorallian sub-divisions of Aporosa and Perforata. The special examination of a large number of intermediate forms among Jurassic corals also enabled her to bring forward many evidences of the phylogenetic relationship of Tetracorallian and Hexacorallian types.

After Moseley (1877) had published his treatise on Millepora, and in the same year J. Carter had pointed out the close relationship of *Hydractinia*, *Parkeria*, and *Stromatopora*, a number of organisms which had been consigned variously to the Bryozoa, and sometimes to the group of Foraminifera, were recognised as Hydrozoa. Steinmann (1878) and Canavari (1893) described new fossil genera from Jurassic and Cretaceous deposits, Bargatzki (1881) described the Stromatoporoids in the Devonian series in the Rhineland, and Nicholson (1886-92) published a monograph of all known Stromatoporoids. The *Graptolites*, an extinct group of Hydrozoa confined to the oldest fossiliferous deposits (Silurian and Cambrian), have been the subject of very careful palæontological investigations. They were taken for Cephalopods by Wahlenberg and Schlotheim, and for Foraminifera by Quenstedt, while others placed them amongst Alcyonarians. Portlock (1843) was the first to recognise their resemblance to the Sertularians. Barrande published (1850) the earliest detailed account of the Bohemian Graptolites, but still compared them with the Pennatulids. The works of Suess, Scharenberg, Geinitz, and Richter extended the knowledge of Graptolites only in a moderate degree; on the other hand, an excellent monograph of the Graptolites occurring in the "Quebec Series" of rocks was contributed by J. Hall in 1865, adding a number of new, well-preserved species to the group, and affording much important information regarding the organisation and zoological position of Graptolites.

In the year 1872 Nicholson gave an admirable survey of all the facts known about Graptolites, and in 1873 the first communications appeared by Lapworth. The researches of this acute observer were continued until 1882, and revealed many new and important data respecting the structure, the

development, the growth, relations, and geological distribution of the Graptolites. All later writings on Graptolites are based upon the results obtained by Lapworth. During the last few years Holm and Wimann have by means of novel methods of technique determined the finest structural features of different Graptolite genera, and R. Rüdemann (1895) made some fortunate discoveries which threw light on the mode of life and the relationship of these remarkable organisms.

Fossil *Medusas* are of very rare occurrence; well-marked impressions found in the lithographic shales of the Franconian Jura Chain have been carefully described by Beyrich (1849), Haeckel (1865-70), and Ammon (1883). Nathorst in 1881 assigned to the Medusas certain casts in the Cambrian sandstone of Sweden, and quite recently (1898) Walcott described a large number of cast structures in the Cambrian deposits of North America as of Medusa origin.

Echinoderms.—In the eighteenth century Klein had proposed for the sea-urchins the class name of *Echinodermata.* Cuvier united under the same class the *Ophiuridea* or sand-stars, the *Holothuridea* or sea-slugs, and the *Encrinites*, without, however, recognising the Encrinites as a separate sub-division. In 1821, J. S. Miller, a native of Dantzig although resident in Dublin, published an excellent monograph on all the fossil Sea-lilies or Encrinites then known, and combined them into an independent sub-division or order which he named *Crinoidea.* In 1828, Fleming erected the order of *Blastoidea* for the Pentremites which had been discovered in 1820 by Say in the North American Carboniferous Limestone, and in 1845 Buch erected the order of *Cystidea* for a group of fossil Crinoids then very little known. Thus the limits and the chief orders of the Echinodermata were definitely established, and at the suggestion of Leuckart in 1848 the class Echinodermata, which had hitherto been treated systematically as closely allied with the Cœlenterata, was represented as an independent branch of descent in the animal kingdom. In addition to Leuckart's fundamental differentiation of these two animal classes, it was he who first combined the Crinoidea, Cystoidea, and Blastoidea under a common group-name *Pelmatozoa*, and placed it in contradistinction to the other sub-divisions of Echinodermata, the Echinidea, Asteridea, Ophiuridea, and Holothuridea.

The systematic study and morphology of the Pelmatozoa was greatly advanced by J. S. Miller's *Monograph of the Crinoidea*, which masterly work constructed a secure basis for all future inquiry into the morphology of the group. Miller made application of the architectural arrangement of the plates in the calyx as a basis of classification, and recent researches have frequently found it advantageous to revive leading features in Miller's classification.

Goldfuss and Münster added a number of new specific descriptions to the knowledge of Crinoidea, but made no attempt to elucidate the structural relations. Three important memoirs were contributed by the anatomist, Johann Müller, on the structure of Pentacrinus (1841), on Comatula (1847), and on the structure of Echinoderms generally (1853). These memoirs were published in the Transactions of the Berlin Academy, and for several decades formed the groundwork of further zoological investigations in this group. Müller included the study of fossil forms in his researches, and he sub-divided the known Crinoidea into three sub-orders—Tesselata, Articulata, and Costata.

Almost simultaneously with Müller's works there appeared in England a monograph of fossil and recent Crinoids by the two Austins (1843). But in spite of many new and valuable observations, this work was unsuccessful, on account of its sub-division of Crinoids into stalked and unstalked groups. This sub-division was regarded as quite artificial, seeing that the gifted zoologist, Vaughan Thomson, had in 1836 demonstrated the development of the genus Comatula from a larval stage resembling a stalked Pentacrinus.

The anatomical structure of the living Pentacrinus was described by Lütken (1864), and that of the Comatulids was elucidated by the researches of Wyville Thomson (1865) and W. B. Carpenter (1866). The deep-sea explorations off the coast of Norway led to the discovery of Rhizocrinus, and the detailed investigation of this interesting genus, carried out by Sars (1868) and Ludwig (1877), met with a cordial reception in palæontological circles.

Numerous monographs and shorter papers on Palæozoic Crinoidea were meanwhile being published; among the more voluminous writers on this subject were De Koninck and Le Hon (1854), Hall (1847-72), Roemer (1860), Ludwig Schulze (1866), Meek and Worthen (1866-75); Mesozoic Echino-

dermata were described by D'Orbigny (1840) and Beyrich (1857). Quenstedt's *Palæontology of Germany* (vol. vi., 1874-76) contains an abundance of new detailed observations but retains the older classification; Angelin's posthumous work on the Swedish Crinoids, edited by Lindström (1878), likewise pays little attention to the results of zoological researches, although it displays a rich diversity of previously unknown forms in its beautiful illustrations. The works of Herbert Carpenter are therefore of very high value as investigations based upon an equal familiarity with fossil and recent forms, and indicating the high-water mark of palæontological and zoological researches at the time. Strictly scientific lines of research have also been adopted in all the more recent works. Two American scientists, Wachsmuth and Springer, have added very considerably to the knowledge of Echinodermata, Wachsmuth's works extending through a period of twenty years, 1877-97; P. de Loriol has made a successful study of Mesozoic forms; in England, F. A. Bather has contributed several memoirs on English and Swedish Crinoids (1890-93); in Germany, O. Jaekel has accomplished valuable new work on Palæozoic Crinoids.

The knowledge of the extinct order of the *Cystoidea*, erected by Buch, was advanced by the researches of Schmidt (1874) on representatives of the group from Russia, by those of Edward Forbes[1] (1848) on British forms, and by the works of Hall and Billings on North American Cystoids. In 1887 Waagen edited a posthumous monograph on the Bohemian Cystoids by Barrande. The systematic arrangement and zoological position of the Cystoids have been discussed in recent years by Haeckel and Jaekel, but the results of their researches are much at variance.

The small group of the *Blastoids*, discovered by Say in 1830, first underwent scientific examination at the hands of Ferdinand Roemer (1852). Subsequent work has extended our know-

[1] Edward Forbes, born 1815 in the Isle of Man, studied medicine and the natural sciences in London, Edinburgh, and Paris, travelled in Algeria, the Alps, and Asia Minor, and conducted in the Ægean Sea his famous investigations on the distribution of marine organisms at the different depths. In 1843 he accepted the Professorship of Botany at King's College in London, and when the Geological Survey was established he was selected as Palæontologist and Professor of Natural History; shortly before his death, in 1854, he exchanged posts with the Professor of Natural History in Edinburgh.

ledge of the specific forms, but could not add much to Roemer's fundamental observations and influences. The illustrated catalogue of the British Museum contains an attractive account of the present knowledge about Blastoids, written by Robert Etheridge and Herbert Carpenter.

The Sea-stars (Ophiuridea and Asteridea) offer far less diversity of form than the Pelmatozoa. If we except a few genera and species mentioned or figured by Goldfuss, Hagenow, Mantell, Dixon, and others, the first scientific monographs on fossil Asteridea were those contributed by Edward Forbes on material derived from Cretaceous and Tertiary formations of Great Britain. Wright afterwards described all the Mesozoic Asteridea, and Salter the Palæozoic forms of Great Britain. Müller (1855) and Roemer laid the foundation of the knowledge of Asteroid types in the Devonian formation of the Rhine Provinces; the Jurassic Ophiuroids and Asteroids of Germany have been investigated by Pohlig, Fraas, and Georg G. Böhm. J. Hall made known the representatives of this group in the Palæozoic formations of North America. The palæontological literature in all cases closely harmonises with the zoological, and it would seem that the Palæozoic "sea-stars" differed very little from those in the seas of the present age.

Fossil Echinids were already known in the beginning of the eighteenth century, and received full attention in the oldest systematic works by Breyn (1732) and Klein (1734). A number of new species are described in the chief work of Goldfuss, in Desmoulin's *Studies* (1834-37), and in Sismonda's monographs on the fossil Echinidea of Piedmont and Nizza. But the strictly scientific literature began with the researches of L. Agassiz (1838-41) on living and fossil sea-urchins, along with which appeared the monograph by Agassiz and Desor[1] on the fossil Echinidea of Switzerland. Valentin's well-known observations on the anatomy and histology of the genus Echinus was contemporaneous with the important works of Agassiz and Desor.

[1] Eduard Desor, born 1811 in Friedrichsdorf, near Frankfort-on-Maine, for a long time collaborated with Agassiz in palæontological and glacial studies, and followed Agassiz to America, but in consequence of some disagreement between the friends, Desor returned to Neuchâtel and became the Professor of Geology in the Neuchâtel Academy. Inheriting considerable means from a brother, he retired to Combe Varin, in Val Travers, and devoted himself to geological and pre-historic studies; died on 23rd February 1882, in Nizza.

A short treatise on the classification of the Echinidea, written by Albert Gras in 1848, was in so far important as it formed the basis of the *Synopsis* of fossil Echinids drawn up by Desor, which has been a standard authority for many decades. In 1848 also, the first researches of Cotteau and Forbes on fossil Echinids were published, and these were rapidly succeeded by D'Orbigny's account of the irregular Echinids of the French Cretaceous formation and Wright's beautifully illustrated monographs of the Jurassic and Cretaceous Echinidea in Britain. After the deaths of Forbes, D'Orbigny, and Wright, Cotteau[1] was for a whole decade almost the only contributor to this field of research. In his *Paléontologie Française*, and in numerous other works and special memoirs, Cotteau advanced the knowledge of the fossil Echinidea in a degree unrivalled by any other observer before or since. All his writings are distinguished by extreme accuracy and acuteness of observation. As regards the systematic questions, Cotteau adopts in great measure the classificatory groundwork supplied by Desor and Wright. A large number of palæontologists have taken up the study of Echinidea in recent years, and the majority follow the lines of Desor's *Synopsis* and Cotteau's results.

The observations on remains of fossil Holothuridea are comparatively few. They are confined to the description of isolated parts of the dermal skeleton, such as the wheel-like spiculæ of certain species of Chirodota described by Moore from the British Jurassic deposits, and several fragments of a similar character, which have been described by Von Siebold, Schwager, Etheridge, and others, occurring in strata of various geological ages.

Worms.—The soft perishable character of the bodies of worms renders them unsuitable for the slow processes of petrefaction, and we find in consequence that palæontological literature contains few references to these organisms, and can bring

[1] Gustave Cotteau, born 17th December 1818 in Auxerre, studied law at Auxerre and Paris, and began his career in 1846 as judge in his native town, in 1857 was transferred to Bar-sur-Aube, in 1858 to Coulommiers, and in 1862 returned to Auxerre as a Member of the Tribunal. Cotteau was regarded as the first authority in the domain of fossil Echinidea; the French Institute in 1887 elected him a Corresponding Member, the Geological Society of France twice elected him President. He died on the 10th August 1894, at Auxerre.

forward little of any scientific value in elucidation of the phylogeny of this diversified group of forms. Fossil Annelid types have been frequently identified and described, and there are impressions or cavities of problematical origin which occur widely distributed in certain Palæozoic deposits, chiefly in Cambrian strata and in the Flysch (Cretaceous-Oligocene) deposits of the Alps, which have been explained by many authors as the paths of worms. Nathorst, however, is of opinion that these cannot be identified with any certainty, but may with equal right be regarded as traces of Crustacea, Mollusca, Annelids, or other organisms. More reliable evidences of fossil Annelids are supplied by the occurrence of fossil Eunicites in the Tertiary deposits at Monte Bolca and in the lithographic shales of Solenhofen. These fossil Nereids are fully described in the works of Massalonga and Ehlers. G. J. Hinde has described numerous jaw parts of Annelids from Palæozoic formations; Hinde points out that, as Zittel and Rohon had shown, these Annelid remains are partly identical with the Conodonts which were regarded by Charles Pander as fish-teeth.

Molluscoidea.—In 1830 Vaughan Thomson discerned the colonial habit of certain small marine organisms which by repeated budding gave origin to the growths popularly termed Sea-mats or Sea-moss. Thomson proposed the name of Polyzoa for the group and compared it with acephalous Mollusca. Ehrenberg in 1834 substituted the name of Bryozoa for the same group. Much later, in 1850, Milne-Edwards united the Bryozoa, Brachiopoda, and Tunicata as one group under the name of Molluscoidea, and assigned to it a rank equal with that of the group of Mollusca. Since then the Tunicates have been recognised as an aberrant branch of Vertebrates, but further researches have only corroborated the probable consanguinity of Bryozoa and the Brachiopoda, while also removing these allies from their supposed connection with the group Mollusca. Fossil Bryozoa were described by Lamouroux, Goldfuss, Lonsdale, and Michelin. In 1850 D'Orbigny, in reviewing the group, tried to separate the fossil and living forms and to make a systematic sub-division accordingly into two orders (Bryozoaires cellulinés et centrifuginés). D'Orbigny's classification is quite artificial; features of subordinate significance are applied as the basis of genera and

families and a number of useless names are invented. The fifth volume of D'Orbigny's *Paléontologie Française* (1850-51) enumerates from Cretaceous deposits no less than 1,929 species and 219 genera, and gives a description and illustration for each species. The publications of MacCoy and J. Hall (1851-52) on Palæozoic Bryozoa, the excellent memoirs of Hagenow (1851) on the Bryozoa of the Maestricht Chalk, and those of Haime (1854) on Jurassic Bryozoa, were but little influenced by D'Orbigny's classification.

Busk passed from a careful anatomical study of living Bryozoa to the study of fossil forms, and began the publication of a monograph describing the Bryozoa or Polyzoa in the English crag. In this monograph, which was unfortunately never completed, Busk sub-divided the forms possessing calcareous cells into two orders (Cheilostomata and Cyclostomata), these two orders almost coinciding with the two chief orders in D'Orbigny's system. But Busk proposed considerable modifications for the minor sub-divisions. For the differentiation of families and genera he used in the first instance the form and arrangement of the "aggregate" or colony, in the next instance the characteristic features of the individual zooecium or cell.

Great progress has been made by zoologists in the knowledge of the internal structure of the polypides, and of the diverse forms of colonial growth. Van Beneden, Smitt, Nitsche, and Hincks have taken a pre-eminent part in the zoological researches, and the whole group has been admirably reviewed by Ray Lankester in the *Encyclopædia Britannica.* Stoliczka and Reuss have contributed largely to the knowledge of Tertiary and Mesozoic Bryozoa, while Lonsdale, MacCoy, J. Hall, and E. D. Ulrich have added much valuable information about Palæozoic types.

The Palæozoic Chætetidæ and Monticuliporidæ have been made the subject of a voluminous literature; some of the most eminent writers, Milne-Edwards, Haime, Nicholson, and Dybowski, consign these groups to the Corals, whereas Lindström, Rominger, and Ulrich place them with the Bryozoas.

In contrast to most classes of the animal kingdom, fossil remains of *Brachiopods* were known earlier than the recent forms. Since the beginning of the seventeenth century, Terebratulites or "Conchæ anomiæ" have played a part in the illustrated works on Natural History. A living

Terebratulina was, however, first made known by Gründler in 1774. Cuvier in 1805, and Duméril in 1809, proposed the name "Brachiopoda" for the class. Lamarck distinguished (1818) only three Brachiopod genera (Orbicula, Terebratula, and Lingula), and erroneously transferred Discina, Calceola, and Crania to the Lamellibranch family of the Hippurites or Rudistes. Blainville, in the *Manuel de Malacologie* (1824), substituted for the Cuvierian name that of Palliobranchiata, and united under this name not only the then known Brachiopods, but also the Rudistes and some fossil Lamellibranchs, *e.g.* Plagiostoma and Podopsis.

In 1834 Leopold von Buch published a memoir *On Terebratulas*, which had a powerful influence. He drew attention to many peculiarities of these shells which had previously been little noticed, and he designed a system of classification based mainly upon the characteristics of the hinge region. This memoir was followed during the next decade by a number of contributions, pre-eminently stratigraphical in tendency, by J. Phillips, Verneuil, D'Orbigny, Barrande, and others. The anatomy of the Brachiopods was made the subject of investigations by Cuvier, Owen (1835), King, Hancock (1858); the finer structure and the internal architecture of the shells was examined by Carpenter (1844), King (1846), and Gratiolet.

King in 1846 drew up a new scheme of classification, using as the chief features of distinction the character of the brachial or labial appendages, the muscular impressions on the inner surfaces of the valves, the septum, and other internal structures. In the monograph of the Permian fossils (1849-50) King completed his system and sub-divided the Brachiopods into three orders, sixteen families, and forty-nine genera. Thomas Davidson[1] simplified and improved King's classification, but adhered to most of the fundamental principles enunciated by his predecessors. The first volume (1851) of Davidson's

[1] Thomas Davidson, born 1817 at Moir House in Midlothian, Scotland, passed his youth for the most part on the Continent, and divided his interest between art and science. He worked in Paris in the atelier of Horace Vernet and Delaroche, and attended the lectures of Élie de Beaumont, Milne-Edwards, and other professors. In Edinburgh he studied natural sciences, and when in Rome on one occasion it was suggested to him by Leopold von Buch to make a special study of fossil Brachiopods, and that became his great life's work. He took up his residence in Brighton, and died there on the 14th October 1885.

series of monographs on the *British Fossil Brachiopods* begins with a masterly exposition of the organisation of living Brachiopods. For this introductory chapter Owen had undertaken the anatomy of living Brachiopod types, and Carpenter the detailed structure of the shell.

The whole series of the *British Fossil Brachiopods* was completed in 1870, the finished work being presented in the form of three handsome volumes published by the Palæontographical Society; the illustrations were drawn by the author himself. Three supplementary volumes were added between 1873 and 1885, and finally Davidson contributed a review of the living Brachiopods and an exhaustive bibliography of the whole group. Davidson's work brought the knowledge of fossil Brachiopods to a higher standpoint of excellence than had been reached by the palæontological knowledge of any other group of Invertebrates. His classificatory system has continued as the standard of all subsequent research.

At the present day the number of palæontologists and stratigraphers who interest themselves in fossil Brachiopods is so large that it is quite impossible to attempt to mention here the more recent widely-scattered literature. It will suffice to indicate the leading tendency in the newer works. Whereas Davidson in his systematic treatment allowed for a considerable extent of variability in his definitions of genera and species, the new direction of research guided by Hall, Clarke, Beecher in North America, and by Waagen and Bittner in Europe, tries to restrict generic and specific definitions within the narrowest possible limits, in order to enhance the value of fossil Brachiopods for the characterisation of stratigraphical horizons. A systematic review of all known Brachiopods forms an introductory chapter in the comprehensive monograph of Palæozoic types which has been published by Hall and Clarke. The number of genera has been greatly increased, and in many cases species have been elevated to the rank of genera. A new classification was proposed in 1889 by Beecher, in which it has been the author's aim to bring the ontogenetic and phylogenetic development of the group into more apparent correspondence, and to apply the differences in the beak region more often for systematic distinctions.

Mollusca.—Palæontology has taken no small share in building up a knowledge of conchology. The study of the

soft parts of living molluscs, as well as the foundation of a natural system of classification, has been reserved for zoology. Palæontology has in all cases followed the results obtained by the sister science, since the group offers considerable facilities for anatomical studies, and there was much more hope to arrive by such means at a true comprehension of this complex and diversiform group. Lamarck, in his *Natural History of Invertebrates* (1816-23), created the modern basis of Conchology, and his proposed system of the Mollusca was supplemented and partially improved by Paul Deshayes in a new edition of Lamarck's work, and in an independent text-book (1839-59), which was unfortunately left incomplete. The chief works of the latter half of the nineteenth century which supply a general account of living and fossil molluscs are those of S. P. Woodward (1851-54), R. A. Philippi (1853), J. C Chenu (1859), W. Keferstein (1862-66), P. Fischer (1889), and E. Ray Lankester (*Encyclopædia Britannica*).

The palæontological literature on fossil mollusca is exceedingly voluminous. Several palæontological monographs are devoted to the detailed description of molluscan faunas characteristic of definite formations, but still more frequently the molluscan forms are treated together with other groups of the animal and plant kingdom in works of a pronounced stratigraphical tendency. Thus it is extremely difficult to extract from the scattered memoirs in Journals and Transactions an accurate historical representation of the advance of palæontological research. The authors who have contributed most to our knowledge of Palæozoic Mollusca are Phillips, MacCoy, Salter, Hall, Billings, Whitfield, Seebach, Barrande, Frech, Waagen, King; Triassic Mollusca have been made the subject of careful researches by Laube, Bittner, Von Wöhrmann; Jurassic Mollusca have been described by Klipstein, Loriol, Seebach, Zittel, Böhm, and others; Cretaceous Mollusca by D'Orbigny, Reuss, Pictet, Renevier, Stoliczka, Müller, White; Tertiary Mollusca by Philippi, Deshayes, Beyrich, Koenen, Wood, Hoernes, Sacco, Morton, White.

The systematic questions have been discussed in detail in the works of Deshayes, D'Orbigny, Pictet, and Stoliczka. A special monograph of *Terrestrial and Fresh-water Conchylia*, by Sandberger, affords an interesting survey of the phylogenetic history of these forms in the course of the geological periods.

Individual classes, orders, or families have sometimes been made the subject of special study. A notable monograph is that by Coquand on the Ostreaceæ of the Cretaceous formation (1869), and several monographs have been devoted to the consideration of the Cretaceous family of the Rudistes. Neumayr in 1891 proposed a classification of the Lamellibranchia based upon the characters of the hinge, and Jackson and Bernard endeavoured to make the developmental history of shells and hinge useful for systematic distinctions.

The literature on fossil Cephalopods is almost too extensive to be reviewed. As far back as 1798, Cuvier had united all the Cuttle-fishes, together with Nautilus and the Foraminifera in one group, which he named *Cephalopoda*, and ranked as a distinct class clearly differentiated from all other molluscs.

The anatomy and morphology of cuttle-fishes was carefully studied by Cuvier and Della Chiaje, and the brilliant anatomical researches of Owen (1832) on the Pearly Nautilus afterwards gave a clear insight into the relationships of the Cephalopoda. Owen sub-divided the Cephalopoda into two orders, the *Tetrabranchiata* with two pairs of ctenidial gills, and the *Dibranchiata* with a single pair of ctenidial gills. To the Tetrabranchs, Owen assigned, in addition to Nautilus and the fossil Nautilites, the large assemblage of the Ammonites. Lamarck in 1801 had differentiated the genera Nautilus, Orbulites, Ammonites, Planulites, and Baculites, and had pointed out the difference between the sutural lines of the chamber divisions in Nautilus and Ammonites. Denys de Montfort (1808), Sowerby, and Parkinson added a few more Cephalopod genera, and De Haan in 1825 classified the known genera under three families (Ammonitea, Goniatites, and Nautilea).

Marked advance was effected by the investigations of Leopold von Buch (1829 and 1839). According to the position of the siphuncle, Buch distinguished two chief groups, Nautilidæ and Ammonitidæ, and sub-divided the latter according to the form of the sutural line into the three sections, Goniatites, Ceratites, and Ammonites. Buch introduced a precise terminology for the various parts of the sutural lobes; he distinguished fourteen families, partly in accordance with the shape and decoration of the shell, partly in accordance with the sutural lines. The spirally-rolled forms were contrasted by Buch with the straight Baculites and the

hook-shaped Hamites, and the various groups were recognised in the classification by the use of descriptive adjectives. Buch also gave a clear exposition of the progressive complication in the sutural lines which could be observed in following the phylogeny of the Ammonitidæ from the Palæozoic epochs through the Mesozoic, and showed how a surmise might be made respecting the age of an Ammonitid genus from the relative degree of complexity in the sutural limits.

Buch's three sections, Goniatites, Ceratites, and Ammonites, were defined by subsequent writers more in harmony with zoological definitions of the group, but the discovery of the rich Triassic fauna of St. Cassian showed that the distinctions between these sections were by no means so sharp as had been supposed. Buch's work undoubtedly gave a new impulse to the study of fossil Cephalopods. The middle decades of the nineteenth century saw the publication of a large number of memoirs, elucidating the genetic relationships of the Palæozoic and Mesozoic genera. The erection of new genera and species went on rapidly, and the necessity began to make itself felt for a further sub-division of the typical genus Ammonites. Barrande, Hall, and other authors had already divided the original Nautilites into a number of genera.

The decisive step of sub-dividing the Ammonites was ventured by Suess in 1865. In a short memoir on the organisation of the Ammonites, Suess converted the adjectival nomenclature of the individual groups of species into names of genera (Phylloceras, Lytoceras, Arcestes), and pointed out that in addition to the sutural line, external form and ornamentation of the shell, there were other features of systematic value, such as the margin of the mouth and the length of the chambers. A similar reform was advocated by Alpheus Hyatt in his memoir on the Liassic Ammonites (1869). The previous nomenclature of families was discarded by Hyatt, and numerous new genera were erected, whose limits were much more narrowly defined than had been customary. As one might have expected, the new tendency met at first with strong opposition, but it was supported and followed by Laube, Zittel, Mojsisovics, Waagen, and Neumayr

Waagen in 1871 combined the Ammonitid genera in eight groups, attributing great importance to the presence or absence of the shell plates termed "Aptychus" and "Anaptychus," and to the particular structure of these remains. Neumayr in

1875 attempted to sub-divide Ammonites into a number of families and genera, but his attempt only served to show how extremely difficult it was to give a precise definition and limit to the individual groups of forms. All groups seemed connected with one another by intermediate types.

Neumayr therefore fell back on the genealogical principle as the guiding feature in his classification, and combined into narrower or wider groups all those forms which in his opinion were either nearly related or directly connected in the line of descent.

Previously to Neumayr, Waagen (1869) had traced the genealogical tree of the species *Ammonites subradiatus* through several stratigraphical horizons, and had proposed the term "mutation" to signify the insignificant variations or modifications apparent in the members more remote from one another in time. The stronger emphasis placed on the phylogenetic relationships introduced a more speculative and subjective character into the study of Ammonites, but it also gave an incentive to a more detailed investigation of the shell development and to a comparison of the ontogeny and phylogeny of these organisms.

Hyatt had endeavoured in the year 1872 to find out the approximate "embryology" of the Ammonites by an examination of the primary chambers and the innermost coils of the shells, and had by this means been able to verify the essential difference between the embryonic development of Nautilidæ and Ammonitidæ which had been stated by Barrande and Saemann. In 1880, Würtenberger emphasised the agreement in the evidences of ontogeny and phylogeny regarding the shell development in the group of Ammonites. Meunier-Chalmas observed (1873) a striking resemblance of the embryonic chambers of certain Ammonites with Spirula, and argued that a near relationship existed between the Ammonites and the Dibranchs. Upon other grounds, Gray, Suess, and to a certain degree also Quenstedt, formed a similar inference; and Steinmann in 1890 expressed his opinion that the genus Argonauta was a lineal descendant of the Ammonites. The development of the chambered shells of the Cephalopods was made the subject of a masterly and comprehensive series of researches by Branco (1881), and led this observer to apply the character of the embryonic chambers as a basis for the chief sub-divisions of the Ammonitidæ.

After Suess and Hyatt had opened the gates for the creation of new generic names, the palæontological literature of the Cephalopods was inundated by innumerable new genera and species, most of them only narrowly defined. The number of species increased in a short time to several thousands. At the same time, new genealogical tables were constantly being constructed, and were as often a little altered and a little improved. The leaders in this extreme movement of breaking up the genera and species are Hyatt, Mojsisovics, and Buckmann.

The Aptychus and Anaptychus remains were the cause of much controversy. Many authors, for example, Scheuchzer, Walch, D'Orbigny, and Pictet, had supposed these plates to be the shells of Cirripedes; Parkinson and Schlotheim had explained them as Lamellibranchs, De Luc and Bourdet as the jaw-bones of some fish, while Hermann von Meyer had ingeniously explained them as parasites of the Ammonites. Ultimately it was universally accepted that they were essential parts of the Ammonites, and they were sometimes looked upon as the internal shells of Dibranchs or Ammonites, sometimes as cover-plates of Ammonites. The latter view, originally advanced by Rüppel, has been confirmed by recently discovered specimens.

Among the Dibranchs, the fossil Belemnites and the forms nearly related to them have received a fair amount of attention in palæontological literature. For many centuries Belemnites had been known and had passed under various designations, "thunderbolts," "devil's-fingers," "lynx-stones," "Lyncurium," etc.; Agricola described them and gave illustrations, and from his time onwards they had a place among the known "petrefactions," although the older authors referred to them as "Echinid" needles, or other organism, or sometimes thought them merely mineral structures. Ehrhardt was the first to compare Belemnites with the shells of Nautilus and Spirula, and De Luc pointed out their resemblance to the enclosed shells of Sepias. The large work of Knorr and Walch contains a good account of Belemnites, and a memoir by Faure-Biguet (1810) gives numerous illustrations of species.

The influence of zoological advances was first clearly shown in the suggestive paper by J. S. Miller (1826) published by the London Geological Society. Soon after, two very good

monographs were contributed by Ducrotay de Blainville (1827) and Voltz (1830). Blainville's monograph begins with a historical review, and proceeds to give an accurate description of numerous species; the monograph by Voltz throws new light on the organisation of the Belemnites. Count Münster (1830), Zieten, Duval-Jonve (1841), Quenstedt, D'Orbigny, and other authors increased the number of known species and arrived at a sharper definition of the different groups of species comprised under the generic name of Belemnite. More recent palæontological work has broken up the old genus and founded several new generic names. Important contributions to the knowledge of the organisation of Decapodous Dibranchs were made by Owen (1844), Mantell (1848-50), and more especially by Huxley (1864). The connection between the extinct Belemnites and living representatives of the group, the Spirulas and the Sepias, was elucidated by these anatomists. An excellent monograph of the "British Belemnites" by J. Phillips (1865-70) appeared in the volumes of the London Palæontographical Society.

Arthropods.—Palæontologically considered, the Crustaceans are the most important group in this branch of the animal kingdom. In the year 1822, Brongniart and Desmarest published a Natural History of the Crustaceans, wherein a clear exposition was given of the zoological and geological significance of these remains. Catalogues of the fossil Crustacea were prepared by H. Woodward and Salter (1865 and 1877), and the whole class was handled by Gerstaecker (1866-74) in a thoroughly scientific and critical manner, chiefly from the zoological standpoint (Bronn's *Classen und Ordnungen des Thierreichs*, vol. v.).

Among the individual orders, the Trilobites have been of the greatest interest for palæontologists. They appeared in the older literature frequently under the names Trinuclei (Lhuyd) and Entomolites (Linnæus), until the name *Trilobites*, proposed by Walch in 1771, came into general use. In addition to the general work of Brongniart and Desmarest, several treatises on the order of Trilobites appeared during the first half of the nineteenth century: the monograph by a Swedish palæontologist, J. W. Dalman, in 1826; by an American author, J. Green, in 1832; by the German authors, Quenstedt (1837), H. F. Emmrich, Goldfuss (1843),

Burmeister (1843), and Beyrich; by the Englishmen, Portlock (1843), Salter, Phillips, and MacCoy; and the Frenchman, Marie Rouault (1847). Dalman and Burmeister proposed a precise nomenclature for the individual parts of the body, and the special terms were still further increased by Beyrich, Salter, and Barrande. For the purposes of systematic arrangement, Dalman and Goldfuss used especially the presence or the absence of eyes, Quenstedt the number of the body segments, Burmeister[1] the capability of rolling up, the characters of the pleura, and the general form of the body. Emmrich proposed to use the external characters of the eyes as a systematic feature, and pointed out the systematic importance of the "facial suture" in the head shield of the Trilobites.

The publication of Joachim Barrande's admirable monograph of the Bohemian Trilobites (1852, and Supplement 1874) marked a great advance in the knowledge of Trilobites. All that had been previously known about these fossil Crustacea is carefully considered in this work, and new observations of high value are added. In so far as Barrande elucidated the constitution of the eyes, the structure of the carapace, the phylogeny of a number of genera, his results have been fully accepted by later authors, but the application which he made of the characters of the pleura in his systematic scheme has not been adopted.

There could be little unanimity of opinion regarding the relations of the Trilobites to the living Crustacea, so long as nothing certain was known about the character of the appendages in the extinct group. Zoologists were always inclined to emphasise the resemblance of Trilobites with living Isopods, but Burmeister pointed out the essential difference between the two orders; after a series of comparative researches he concluded that the "feet" of the Trilobites had been of a soft character, much as is now presented in the Phyllopods, and that in many respects the Trilobites showed close affinity with the Xiphosura. Gerstaecker assigned (1879) the Trilobites to the Entomostraca (Gnathopoda) as an independent

[1] Hermann Carl Burmeister, born 1807 at Stralsund, studied Medicine and Natural Science in Greisswald and Halle, began his career as a gymnasium teacher and University tutor in Berlin; in 1837 became extra-Ordinary Professor of Zoology in Halle, in 1842 full Professor; in 1850 and 1856 travelled to Brazil, the Argentine and Chili, and in 1861 was called to Buenos Ayres to be Director of the Natural History Museum, which he had been instrumental in establishing; died there 1892.

order; Beneden, Dohrn, Haeckel, Walcott, and others gave still more weight to the homologies with the Xiphosura, and associated the Trilobites with this order in the classification. Billings' discovery in 1870 of ambulatory appendages in a specimen of Asaphus from the Trenton limestone was followed by further discoveries of Trilobite walking-appendages by Walcott (1879). Afterwards antennæ were found, and well-preserved specimens formed a basis of more detailed descriptions of the jaw and ambulatory appendages by Matthew (1893), Beecher (1894), and Walcott (1894). Thus, within recent years, Burmeister's conception of the classificatory position of the Trilobites has been in many respects verified, although many palæontologists still regard them as prototypes of the Isopoda.

Excellent reports and monographs on the genealogico-morphological relations of the Trilobites have been contributed from time to time by Dr. Henry Woodward, whose monograph on the British Trilobites, prepared in collaboration with Salter, is a standard work on this group.

Charles Darwin established the knowledge of fossil Cirripedia (1851-54) upon a scientific basis, and subsequent publications by Bosquet, Reuss, Seguenza, and other palæontologists follow the views advanced by Darwin.

Many memoirs have been devoted to fossil Ostracods, but their interest is almost exclusively stratigraphical.

Under the name of Merostomata, the Xiphosura and the extinct ancestral order of the Eurypterida are usually combined. Dr Woodward has made signal advances in the knowledge of this group of Crustacea by his admirable monographs which appeared in the volumes of the Palæontographical Society between 1866 and 1878. The first accounts of the Palæozoic Eurypterids were communicated by Dekay, Harlan (1825), and Scouler (1831). The systematic relationship of the fossil Eurypterids with the living Limulus (King-Crab) was recognised by F. Roemer (1848) and MacCoy (1849), and the memorable anatomical researches of Thomas Huxley afterwards threw new light on the evolution of the Merostomata. Although of less commanding interest, ample justice has been done in palæontological literature to the fossil Phyllocarida, or the ancestral forms of the Branchiopoda, and also to fossil Isopoda, Amphipoda, Stomapoda, and Decapoda.

The literature on fossil air-breathing Arthropods is, like that on the Crustacea, in recent years passing more and more into the hands of the zoologists, and it is in consequence vastly increasing in its intrinsic interest and merit. Myriopod remains were first discovered in the amber layers and gypsum series of Aix, and in 1845 were also found by Westwood in the British Carboniferous deposits; in 1854, C. L. Koch and J. C. Berendt published the first important monograph on the Crustacea, Myriopoda, Arachnida, and Apterida fauna contained in these deposits, and this was afterwards followed by the excellent works of W Dawson (1859), H. Woodward (1871), Peach, and Scudder.

Palæontologists have contributed a large number of memoirs descriptive of fossil insects. A handsome monograph by E. F. Germar (1844-53) was devoted to the remains of insects occurring in the Carboniferous formation of the Halle neighbourhood. Dana drew attention to the Carboniferous insect fauna of the Illinois district, and the same fauna was afterwards more carefully examined by Scudder. The most important addition to our knowledge of Palæozoic insects was made by C. Brongniart in his brilliant monograph on the remarkable and often gigantic forms discovered in the Carboniferous rocks at Commentry. The numerous fossil insects found in the lithographic shales of Solenhofen were described by Count Münster, Germar, Oppenheim, and Meunier. The British insects of the Mesozoic deposits were examined by Brodie and Westwood, and several authors have published accounts of the fossil insects in the Tertiary deposits of different countries.

Vertebrata.—Undoubtedly palæontology has achieved its greatest successes in the domain of vertebrate animals. In the very beginning of the nineteenth century, Cuvier had established such an admirable groundwork of research that it was made almost impossible for any one who lacked a thorough scientific training to attempt to continue a work so gloriously begun. Thus the number of authors who have occupied themselves with fossil Vertebrates is at once unusually small and exceedingly select, with the result that the average quality of the works in this department of palæontology is of a very high order. A general account of fossil Vertebrates will be found in Owen's *Palæontology* (1860), in

P. Gervais's *Zoologie et Paléontologie Française* (1848 to 1852), in Albert Gaudry's *Enchaînements du monde animal dans les temps géologiques* (1878-96), in Zittel's *Handbuch der Paläontologie* (vols. iii. and iv., 1887-93), in Lydekker and Nicholson's *Manual of Palæontology* (vol. ii., 1889), and in Smith-Woodward's *Outlines of Vertebrate Palæontology* (1898).

A highly instructive line of original research was carried out by Owen in his comparative study of the teeth of fossil Vertebrates, and important advances were made by the publication of his *Odontography* (1840-45). This work provides a fundamental exposition of the teeth in the different classes, orders, and families of the Vertebrates. A similar work by C. G. Giebel (1855) is far from equalling its English model either in respect of its illustrations or its original observations.

The scientific knowledge of *Fishes* may be said to have begun with the pioneer researches of Ray and Willoughby in the seventeenth century. These zoologists, who were the first observers to distinguish definite "species" in the organic world, laid the foundation of empirical details regarding fishes in their famous *Historia piscium* (1686). Artedi (1705-34), a contemporary and fellow-student of Linnæus, made an excellent classification of the genera known in his time. Towards the close of the eighteenth century, Dr. Bloch's system of classification was in great favour, although his work on fishes was far less notable than that of his French contemporary, Lacépède. But a complete reform was necessitated by Cuvier's searching anatomical investigations, and the system of Cuvier and Valenciennes superseded all previous systems. In common with the earlier system, the Cuvierian classification was founded exclusively upon living forms. What was known of fossil fishes was inserted along with the living genera, in whatever position seemed most expedient to the particular author from his examination of external features.

The famous investigations of L. Agassiz (1833-43) supplied palæontology with a much broader basis of detailed research. Accompanied by capable draughtsmen, Agassiz visited all the larger museums and private collections in Europe, examined the fossil fishes preserved in them, and published, in five volumes, a magnificently illustrated monograph as the fruits of his ten years' labour. Starting from the standpoint of his anatomical studies, in which he was fortunate in having the

assistance of C. Vogt, Agassiz was enabled to elucidate many obscure points in fossil fishes. Agassiz also introduced emendations in the classification of recent fishes, and added many new data regarding the evolution and the range in time of the various families. His sub-division of fishes into Placoidei, Ganoidei, Cycloidei, and Ctenoidei, according to the scaly skeleton, was certainly one-sided and artificial, and had to be discarded. At the same time, Agassiz conferred a great boon when he brought the Ganoidei into the strong relief of a sub-division, and insisted upon their importance both as essential links in the phylogenetic history of fishes and as a group comprising many specific types of high value for the characterisation of geological horizons. Agassiz was the first scientist who, in discussing the genealogy of fishes, pointed out the correspondence between the characters of different forms succeeding one another in time, and the characters of successive phases passed through by an organism during embryonic development. The observation was one of those far-reaching truths which are now and then wrested from nature; Haeckel worked out the same idea and elevated it to its merited rank as a fundamental bio-genetic principle. Hence, although the actual classificatory system proposed by Agassiz for the fishes could not supersede the Cuvierian system, and was soon appreciably changed for the better by Johann Müller's valuable works (1844), the name of Agassiz will always be among the most honoured in ichthyological literature. A later monograph on the remarkable fishes of the Old Red Sandstone was in many respects supplementary to the earlier work of the Neuchâtel *savant.*

A large number of special memoirs followed the works of Agassiz and Müller, and gave a greater insight into the remarkable varieties and wide distribution of the remains of fossil fishes. Those of Grey Egerton, Count Münster, Andreas Wagner (the Director of the Museum of Natural History in Munich), Costa, Thiollière, Pictet, Von der Marck, Kner, Zigno, Steindachner, H. von Meyer, Traschel, are all works of high palæontological merit. Pander's monographs on the fossil fishes of the Silurian and Devonian deposits in Russia (1856 and 1858) are distinguished by exceptional discernment, and by the wonderfully successful drawings of the microscopic structure of teeth and scales. It proved a difficult matter to determine the essential characters of

the Ganoids. The bony, angular scales which Agassiz had regarded as the chief systematic feature was not in itself sufficiently distinctive, as living Teleostei possess bony scales. Johann Müller and C. Vogt strengthened the systematic definition of the Ganoids by anatomical features; Müller showed that the Ganoids agreed with the Plagiostomes, and differed from the Teleosteans in the structure of their heart. This step in the right direction was not, however, immediately followed by palæontologists, who on the contrary persistently continued to place the Ganoidei in close affinity with the Teleostei.

A preliminary paper on "Devonian Fishes" was published by Huxley in 1861, and was followed five years later by his memorable work on the *Structure of Crossopterygian Ganoids*, wherein he showed the relationship of these forms to the Dipnoi. Huxley regarded the genus Lepidosiren as a living representative of the ancient Ganoids; and in 1870 the living genus Ceratodus was discovered, and its careful anatomy and description (1871) by Günther showed that the new genus was closely allied with Lepidosiren, and that both must be assigned to the Ganoidei. The more accurate knowledge thus secured reacted favourably on the advance of a sound systematic knowledge of the fishes.

The monograph by Traquair (1877) on *The Ganoids of the British Carboniferous Formations* made known one of the richest and best preserved Ganoid faunas. The Selachian fishes were made the subject of a comprehensive series of researches by Hasse on the structure and the development of the vertebræ; O. Jaekel has contributed an excellent monograph of the Selachian remains from the Tertiary rocks of Monte Bolca; and O. Reis has written valuable memoirs on Cœlacanthidæ, Acanthodidæ, and other fossil groups. An admirable catalogue of the fossil fishes in the British Museum is in course of preparation by Smith-Woodward, one of the first authorities on fossil fishes. The volumes already published (1889-95) present, so far as they go, an exhaustive and critical review of all fossil fishes.

Amphibians.—The works of Alexandre Brongniart (1805) and Blainville emphasised the fundamental differences between Amphibians and Reptiles anatomically, and in respect of the history of their development; but it was Merrem who, in 1820,

for the first time placed the Amphibians and Reptiles in two separate groups of equal value in the classificatory system. In the eighteenth century, fossil Amphibians had been found in the Tertiary marls of Oeningen. In the year 1828, G. Jaeger described the teeth and part of the skull of a gigantic Salamander. These remains, found in the Triassic Alaun shales of Gaildorf, were the first discoveries of Amphibians in Mesozoic epochs, and later discoveries of Amphibian remains were made in the Bunter Sandstone of Sulzbach, and the Keuper strata near Bayreuth (1836).

In the year 1841, Owen published two memoirs on teeth showing a labyrinthic structure, and on several skeletal remains found in the Keuper of Warwickshire; Owen united these remains under the name of Labyrinthodon, and asoribed them to gigantic Batrachians. H. von Meyer and Plieninger, in a *Monograph on the fossil Labyrinthodonts of Wurtemberg* (1844), added much valuable information regarding the structure of the skull, the dental arrangement, and the skeleton of this animal. After a careful comparison of the Labyrinthodonts with reptiles, Amphibians, and fishes, Meyer formed the opinion that, in spite of many points of resemblance with Amphibians, the Labyrinthodonts belonged to the Reptiles. This view was retained by Meyer even after his detailed investigation of the Triassic Saurians (1847).

Burmeister published (1848-50) special memoirs on the Labyrinthodonts from the Bunter Sandstone series at Bernberg and the Carboniferous rocks at Saarbrücken, and expressed his opinion that the Labyrinthodonts represented mixed types of Reptiles and Amphibia. Ten years later, Meyer described the same forms in a monograph which is one of the best works on Palæozoic Vertebrata. The osteology of the Carboniferous genus Archegosaurus was fully and accurately depicted, and an excellent exposition was given of the incompletely ossified vertebræ and the several pieces constituting them. Larvæ with persistent gills were described, but nevertheless Meyer still relegated the Labyrinthodonts to the Reptilia.

Some new forms were discovered in the Carboniferous formation of Nova Scotia and Ohio, as well as in the Permian rocks of Silesia, and Owen, on the basis of his examination of these, erected (1861) two orders—the *Ganocephali*, comprising Palæozoic forms with incompletely ossified vertebræ, persistent

gills, and cartilaginous occipital region; and the *Labyrinthodonti*, comprising the younger Labyrinthodonts. Dawson added a third order, the *Microsauri*, whose remains occur in the Carboniferous rocks of Nova Scotia, Ohio, and Illinois. A few complete skeletons of Palæozoic Amphibians from Ireland were described by Huxley (1860-67), in addition to different Labyrinthodonts from deposits in Australia, South Africa, and India.

In the year 1869, E. D. Cope united all known Palæozoic and Mesozoic Amphibians under the name of *Stegocephali*, and added a fourth order, *Xenorhachia*, characterised by soft vertebræ. Miall, in 1873-74, made somewhat unsatisfactory attempts to remodel the classification of the Amphibians. A rich discovery of Amphibian remains in Bohemian and Moravian Permo-Carboniferous deposits formed the subject of an admirable monograph by A. Fritsch, wherein many new genera are described in considerable anatomical detail. A few years later, in the "Red Underlyer" horizon of the Permian deposits at Niederhässlich, near Dresden, Hermann Credner discovered a dolomitic bed with numerous Stegocephali in excellent state of preservation. The examination of these occupied many years; the results appeared between 1881 and 1893 in the *Zeitschrift* of the German Geological Society, and considerably advanced the knowledge and the systematic treatment of the group. From time to time material is found in a good state of preservation, and the number of known species of Palæozoic Stegocephali found in Europe has steadily increased.

In North America, also, new material is frequently found. Cope's investigations of the remains of Stegocephali in the Permian deposits of Texas induced him to propose a classification based chiefly on the different characters of the vertebræ, and many of his suggestions have been adopted in Zittel's and Credner's classifications. New discoveries of Stegocephali occur less frequently in the Mesozoic deposits. E. Fraas published (1889) a monograph of the Swabian Triassic Labyrinthodonts, based on the excellent material in the museum at Stuttgart, and R. Lydekker described various remains from the Triassic deposits of India and South Africa. The fossil Urodeles in Cretaceous and Tertiary deposits have been made the subject of monographs by H. von Meyer, Goldfuss, Lartet, Dollo, and others; while Cope, H. von Meyer, Filhol, and Woltersdorff have studied fossil Anura.

Reptiles.—As early as the year 1812, Cuvier had given a full exposition of all reptiles known up to that date, and had elucidated in a masterly manner the osteology of the Ichthyosaurians, Plesiosaurians, Crocodiles, Mosasaurians, Lizards, Tortoises, and Pterodactyles. And as the systematic arrangement of living reptiles had already reached a standard of security, the fossil discoveries could the more easily be grouped according to their apparent affinities. In the year 1830, Von Meyer made the first attempt at a systematic classification of living and fossil reptiles. Meyer consigned all fossil reptiles, with the exception of tortoises and serpents, to the Saurians, and sub-divided the Saurians into Dactylopoda, Nexipoda, Pachypoda, Pterodactyli, and Labyrinthodonti.

This classification was soon changed by Owen.[1] This great anatomist opened his magnificent series of researches on fossil reptiles in the year 1839; his works on this subject extend over a period of fifty years, and have been a source of remarkable scientific progress. Owen erected a number of orders of fossil reptiles, and gave to them an equal value with the orders of living reptiles. His systematic sub-division, with a few changes afterwards introduced by Huxley, Cope, Marsh, and Baur, has retained its authoritative position to the present day. All fossil reptiles occurring in Great Britain were described by Owen in a long and profusely illustrated series of monographs published in the volumes of the Palæontographical Society; he also examined and described the remarkable reptilian remains from the Karroo formation in South Africa.

Meyer supplied an exhaustive account of all reptiles occurring in Germany. This indefatigable palæontologist published four large monographs of the fossil Saurians between 1847 and 1860, and in addition contributed many other memoirs, illustrated by his own drawings, to the volumes of

[1] Sir Richard Owen, born on the 20th July 1804, in Lancaster, studied medicine, and especially surgery, in Edinburgh and London; became in 1828 assistant at the College of Surgeons in London, and in 1834 Professor of Comparative Anatomy. The Geological Society in 1838 presented the Wollaston medal to the young scientist, and in 1857 he was chosen President of the British Association for the Advancement of Science. In the year 1856 he resigned his Professorship at the College of Surgeons, and accepted the post of a Director of the British Museum. In 1881 the Natural History Collections were transferred to the new buildings at South Kensington, and Sir Richard Owen was director of that department. He died on the 18th December 1892.

the Palæontographica. Along Cuvierian lines, Meyer and Owen extended in Europe the knowledge of fossil reptiles, while the able American palæontologists, J. Leidy, O. C. Marsh, and E. D. Cope, were at work on the reptilian remains of North America.

The osteology of the Jurassic Ichthyosaurians was early elucidated by Conybeare, Hawkins, Buckland, Owen, Jaeger, Bronn, and others; valuable work on this group of Saurian has been more recently contributed by Seeley, G. Baur, and E. Fraas. The Plesiosauridæ, Nothosauridæ, and Rhynchocephali have also been carefully investigated by palæontologists. A classical treatise by Huxley (1875) signally advanced the knowledge of the genetic relations of the fossil and living crocodiles. The Triassic Parasuchia were made known by Meyer, Huxley, and Cope, the Pseudosuchia by O. Fraas, and more recently by the careful and accurate studies of E. T. Newton (1894). Jurassic and Cretaceous crocodiles have been treated by Koken and Dollo, and the Tertiary forms by Vaillant, Lydekker, and Toula, in addition to Meyer, Owen, and other earlier authors.

Palæontological literature is more limited regarding fossil lizards and serpents. The Mosasauridæ or Pythonomorphs, whose affinities with the lizards were recognised by Cuvier, were afterwards elevated to the rank of a separate order by Cope, and have formed the subject of several important memoirs by Marsh, Cope, Owen, Dollo, Merriam, Williston, and Gaudry. Remains of the winged Saurians had been known in the eighteenth century, but it was Cuvier who first recognised that their systematic position was among the Reptilia. The exquisitely preserved skeletons from the lithographic shales of the Franconian and Swabian Jura aroused great interest, and were the subject of many excellent memoirs by Count Münster, Goldfuss, Meyer, Wagner, Fraas, Marsh, Zittel, Ammon, and others. Liassic Pterodactyles were described by Buckland, Theodori, Owen, and Plieninger, and Jurassic and Cretaceous forms were carefully examined by several of the leading authorities among British and American palæontologists.

The gigantic, extinct Dinosaurs were discovered relatively late. Buckland, in 1824, made known the first remains of this order under the generic title of Megalosaurus. In the following year, Mantell discovered the remains of Iguanodon

and Hylæosaurus in the fluviatile Weald clays of Sussex, and Owen, in 1841, proposed to comprise the genera then known as a distinct order under the name of Dinosauri. Further discoveries continued to increase the number of known genera, and in 1866 Cope divided the Dinosauri into three sub-orders (Orthopoda, Goniopoda, and Symphypoda). In a series of very important memoirs devoted to the osteology, classification, and genealogy of the Dinosaurs (1868 and 1869), Huxley pointed out the essential affinities of the Dinosaurs with birds, and even designated the genus Compsognathus as a uniting link between this extinct group of reptiles and the younger and more specialised group of birds.

Ten years later, Marsh began to publish the results of his examination of Dinosaur specimens which had been discovered in extraordinary number, and often in a perfect state of preservation, in the western states of North America. Marsh conducted his researches for twenty years, and inaugurated a sweeping reform of the classificatory system of Dinosaurs. Alongside this memorable discovery of Dinosaurs in North America, Europe can place the discovery of twenty-three wonderfully preserved skeletons of Iguanodon near Bernissart. These were carefully disinterred under the guidance of Dupont, and afterwards excellently described by Dollo. Besides the authors already named, Hulke, Seeley, Lydekker, and Baur have made valuable contributions to the knowledge of this interesting extinct order of Saurians.

Under the name of Theromorpha, Cope, in 1880, erected a new order of Reptiles, in which he placed rather an ill-assorted assemblage of fossil forms. The Placodonts from the Muschelkalk were the first known representatives of this order, but notwithstanding the memoirs of Münster, Braun, Meyer, and Owen, the affinities of the Placodonts are still very obscure. As yet the skull, jaws, and teeth are the only parts of the skeleton that have been found.

In the year 1859 Owen erected the order of Anomodontia, for certain remarkable fossil Reptilian remains which had been discovered in South Africa by G. Bain as far back as the year 1838. Afterwards Owen (1876) separated the Theriodontia from the Anomodontia, and erected it as an independent order characterised by numerous well-differentiated teeth. Owen then devoted a special monograph to all the Reptilian remains from the Karroo formation in South Africa, and his

work in this direction has been supplemented by the more recent monographs of H. G. Seeley. In 1880, Cope described several representatives of Theromorpha from the Permian deposits of Texas, and E. T. Newton has recently made known some remarkable genera of Anomodontia from the Triassic Sandstones of Elgin in Scotland.

Birds.—Cuvier gave an account of the few remains of fossil birds that were known in the beginning of this century. A general review of the geological distribution of birds was contributed by Milne-Edwards (1863), who also provided, in a large monograph (1867-72) of the fossil birds of France, an osteological basis for the study of this class. In the year 1860 a fossil feather was discovered in the Jurassic shales of Solenhofen, and a year later at Eichstatt a whole skeleton of the oldest fossil bird was found. It was, however, described by A. Wagner as a winged reptile. Sir Richard Owen (1863) recognised in it the characters of a true bird, notwithstanding the long tail and the peculiarly constructed front extremities; several palæontologists thought it intermediate between birds and reptiles. A second specimen of Archæopteryx was found at Eichstatt in 1877; it was obtained by the Berlin Museum and described by Dames (1884). In 1875, Marsh drew attention to the occurrence of toothed birds in the Cretaceous rocks of Kansas, and published a monograph in 1880 with excellent illustrations of these Odontornites. The remarkable fossil giant birds of New Zealand were described in detail by Owen (1849-86), and the powerful Æpyornites of Madagascar were studied by Bianconi, Grandidier, and Milne-Edwards. The comprehensive work of Fürbringer (1888) contains a full exposition of the phylogenetic relations of fossil and living birds, and is of the utmost importance for the morphology and classification of birds.

Mammals.—No sub-division of Palæontology was so far advanced in the beginning of the nineteenth century as that of fossil Mammalia. Cuvier's famous investigations on fossil bones (*ante*, p. 135) not only contain the principles of a Comparative Osteology, but also show in a manner that has never been surpassed how fossil Vertebrates ought to be studied, and what are the broad inductions which may be drawn from a series of methodical observations. A consider-

able part of the fossil mammals that occur in Europe are exhaustively described in Cuvier's classical work, and until Darwin began to interest himself in the palæontology of the fossil Mammalia, the study continued to be followed entirely along the lines indicated by Cuvier. The *Osteology of Recent and Fossil Mammalia*, a large work in four volumes by Ducrotay de Blainville,[1] was prepared strictly after the model of Cuvier's writings, although the copy comes very far short of the original. Still Blainville had at his disposal unusually rich fossil material, and his illustrations were prepared by draughtsmen of exceptional skill and technique. In artistic treatment and scientific accuracy, the plates which accompany Blainville's *Osteology* are perhaps only surpassed by the magnificent drawings of the skeletal parts of recent mammals by Pander and D'Alton (1823-41). Giebel's *Fauna der Vorwelt* contains in the first volume a concise and faithful account of all the fossil Mammalia known up to the year 1847. A newer summary of the subject is comprised in R. Lydekker's *Catalogue* of the fossil Mammalia in the British Museum (1885-87), and a still later account in the *Introduction to the Study of the Living and Fossil Mammals* (1891) by Flower and Lydekker. An enumeration of all known fossil Mammals was drawn up by O. Roger (1887 and 1896).

In contrast to Cuvier's anatomical and descriptive mode of treatment, Gaudry, in the first volume of his work, *Enchaînements du Monde Animal* (1878), aimed rather at elucidating the genealogical relations of fossil Mammalia in an attractive manner, and at demonstrating the gradual transformation of certain types in the course of the geological periods. Many writers on fossil Mammalia, among others Huxley, Rütimeyer, Cope, and Marsh, have brought forward weighty evidence in favour of Darwin's theory of the descent of man.

In Germany, Goldfuss and G. Jaeger (1835) published *Contributions to the Knowledge of the Fossil Mammals* found in the Diluvial deposits and in the Tertiary series of Swabia. The monographs of J. J. Kaup (1832-61) described the

[1] Henri Marie Ducrotay de Blainville, born 1778 in Argus near Dieppe, studied Medicine in Paris, was Professor of Comparative Anatomy and Zoology at the Normal School, and in 1832 succeeded Cuvier as Professor of Comparative Anatomy at the Botanical Garden; he died suddenly in 1850 in a railway compartment, while travelling between Paris and Rouen.

Tertiary Mammals of the Mainz basin, and also the remarkable fauna from Eppelsheim, near Worms. Simultaneously with Kaup, H. von Meyer began his palæontological writings with a memoir on fossil antetypes of the horse (Hipparion) found at Eppelsheim, and on Cervus Alces and Dinotherium Bavaricum (1832). Other monographs followed, describing fossil Mammalian teeth and bones from Germany and from different parts of the world. A. Wagner, the Munich palæontologist, has the credit of having first made known the rich Mammalian fauna of Pikermi, near Athens (1848-57); his works were afterwards superseded by Gaudry's excellent monograph (1862-67), wherein a fuller material collected by Gaudry himself is accurately described and discussed. By the death of H. von Meyer, Germany lost its best authority on fossil Mammalia. The gap was to a certain extent filled by Quenstedt and O. Fraas in Würtemberg, who carried out a careful revision of Jaeger's preliminary account of the well-preserved Mammalian remains from the Swabian Alp and the fresh-water limestone of Steinheim (1870 and 1885). In recent years, M. Schlosser, O. Roger, Koken, W. Branco, and Pohlig are the leading German authorities in the research of fossil Mammals.

In Austria-Hungary, Peters, Suess, Toula, A. Hofmann, Weithofer, Woldrich, and others have contributed valuable memoirs on the knowledge of Tertiary Mammals. The fauna of the Belgian caves was admirably described by P. S. Schmerling (1833-46), and similar investigations on the Diluvial Mammals of France were conducted by M. de Serres, Lartet, E. Chantre, and Lortet. France has always fostered the palæontological research of fossil Mammals. The fundamental works of Cuvier and Blainville were followed by a large number of special memoirs. P. Gervais (1848-52) published a work on the zoology and palæontology of the Vertebrates occurring in France. The Mammalian remains of the Department Puy-de-Dôme (1828) were made the subject of special monographs by Croizet and Jobert; Pomel described those of the Rhone basin (1853); Edouard Lartet described the Miocene fauna of Sansan; H. Filhol the rich Mammalian fauna of the phosphorus beds in the Oligocene deposits of Quercy and neighbouring localities; and V. Lemoine described the oldest Mammalian fauna of France occurring in the Lower Eocene rocks of Cernays, near Rheims.

One of the most celebrated palæontologists in the domain of fossil Mammalia was Rütimeyer,[1] in Bâle. His works cover a wide field of research and hold a high place in the literature. Some of the best known are his monographs on the fauna of the lake-dwellings (1862), his contributions to the Comparative Odontography of the Ungulata (1863), his memoirs on the genealogy of the Mammalia (1867), his discussion of the affinities between the Mammalia of the Old and New Worlds (1888), and his *Contributions to a Natural History of the Ruminants* (1865), *of Oxen* (1866-67), and *of Deer* (1881). Rütimeyer is a convinced although cautious adherent of the Darwinian theory of evolution. His genealogical trees of the Mammalia show a complete knowledge of all the data concerning the different members in the succession, and are amongst the finest results hitherto obtained by means of strict scientific methods of investigation.

In Great Britain, Buckland provided in his *Reliquiæ Diluvianæ* (1823) the earliest general account of the Mammalian remains in the caves and the Diluvial deposits of that country. After the production of Owen's *Natural History of the British Fossil Mammals and Birds* in 1846, that observer was universally recognised for nearly half a century as the greatest living authority on Mammalia. Throughout his long and active career, Owen contributed an extensive literature on British, Australian, South American, and Asiatic fossil mammals. Special interest was aroused by his memoir in 1891 on the oldest known Mesozoic forms, from the Stonesfield and Purbeck horizons of Jurassic rock. Another zealous British palæontologist was Dr. Falconer, whose *Fauna Sivalensis* (1846-49), written in collaboration with Cautley, disclosed a new and extremely rich Mammalian fauna from the younger Tertiary deposits of India. After Dr. Falconer's death, Charles Murchison collected several of his important memoirs on fossil Rhinoceroses and Proboscideans, and published them posthumously in one volume (1868). In more recent years, Busk, Flower, Lydekker, Boyd Dawkins, and

[1] Ludwig Rütimeyer, born on the 26th February 1825, at Biglen, in the Emmen Valley, the son of a pastor, studied at first theology, then medicine, at Bern University, but showed a preference for geology, zoology, and palæontology. In 1853 he was appointed extra-Ordinary Professor of Comparative Anatomy in Bern, and in 1855 Professor of Zoology and Comparative Anatomy at Bâle; he died at Bâle on the 25th November 1895.

Leith Adams have been engaged in the palæontological research of fossil Mammalia.

The broad plains of Russia have afforded numerous specimens of Diluvial fossil Mammals, the Tertiary formations in the vicinity of Odessa and Bessarabia have yielded remains of the oldest fossil Mammals, more especially of Cetacea and Pinnipedia. The leading investigators of these remains have been J. F. Brandt, A. von Nordmann, and M. Pavlow. A rich fossil Mammalian fauna was discovered by Forsyth Major (1887) on the island of Samos, in formations contemporaneous with those of Pikermi.

Many Mammalian remains in the Diluvial deposits of North America were known as early as the eighteenth century. In the year 1857 Emmons discovered the famous Dinotherium jaw from the Triassic rocks of Virginia. A strict scientific investigation of fossil Mammalia was first inaugurated in North America by Joseph Leidy, the late Professor of Anatomy at the University of Philadelphia. In the year 1853, Leidy's *Monograph on the Mammalian Remains of Nebraska* revealed a fauna quite different from all European faunas then known. Two later works (1869 and 1873) showed that Mammalian faunas, of which no one had previously any conception, were interred in the successive Tertiary deposits in the Far West of North America.

The excellent publications of Leidy inspired O. C. Marsh and E. D. Cope to begin in the early seventies their prolonged series of valuable researches on the fossil Mammalian faunas in the Far West. Immense sums of money were required, and were readily procured, for the disinterment of the fossil remains. To the penetration of Marsh[1] and his well-trained collectors, palæontology owed the discovery of

[1] Othniel Charles Marsh, nephew of the rich philanthropist Peabody, was born on the 29th October 1831, at Lockport, in New York State; studied in Yale College at New Haven, in Berlin, Heidelberg, and Breslau, and travelled in Germany, the Alps, and other parts of Europe during his student days. After his return to America, he was in 1866 appointed Professor of Palæontology at Yale University, and Director of the Geological and Palæontological Department of the Museum founded by Peabody, a post which he occupied for thirty years. He organised numerous expeditions to the Far West, which was then a most inhospitable region, and secured over a thousand new species of fossil Mammalia. He bequeathed his private collection, formed at his own expense, to the Peabody Museum. The specimens collected at the expense of the State are now in Washington. He died at New Haven, in March 1899.

a richly diversified micro-fauna of mammals in the Upper Jurassic deposits, and a similar fauna in the youngest Cretaceous horizons of Wyoming and Colorado. A monograph, with plates of very high excellence, was devoted by Marsh (1884) to the description of the gigantic Dinocerati, which form a group of fossil Mammalia peculiar to North America. A large number of memoirs by Marsh appeared in successive publications of the *American Journal of Sciences*, and made known the important results of his researches on the interesting faunas of the Far West.

Contemporaneously with Marsh, his indefatigable rival, Cope, also worked at the fossil Mammals of the Western States. Unfortunately these two highly-gifted palæontologists were not on friendly terms, and it frequently happened that their works on special genera and species overlapped. Cope's greatest interests were systematic, and he made several improvements in the classification of the higher Mammals. His two reports on the extinct Vertebrates in New Mexico (1874) and on the Vertebrates of the Tertiary formations in the Western States (1884) contain an extraordinary wealth of new observations. Cope discovered a new fauna in the so-called Puerco formation, the oldest horizon of the American Eocene deposits.

Cope's work comprised the fossil Mammalian remains found in Mexico, Central America, and the West Indies. In Brazil, a Danish geologist, P. W. Lund, discovered and described (1841-45) a diversified fossil Cave Fauna. The wide Pampas in the Argentine, in Uruguay and Paraguay, proved to be a rich field for the remarkable fossil Edentate forms. The osteological characters of the gigantic fossil Sloths found abundantly here and in the Pleistocene deposits of other parts of North and South America have been investigated by Owen, Gervais, D'Alton, Huxley, Flower, Nodot, H. von Meyer, and more recently by H. Burmeister (1864-81), J Reinhardt (1875), and Florentino Ameghino.

Next to the discoveries of Mammalian faunas in the west of North America, the most important palæontological event of the two last decades of the nineteenth century has been the disclosure made by Florentino Ameghino of a rich Mammalian fauna in the Tertiary rocks of Patagonia. New forms are constantly being added from the inexhaustible fossil localities in the province of Santa Cruz. The fauna is being described entirely by

its discoverer Ameghino, and has already thrown great light on the relations and real affinities of the existing South American fauna. In Australia also, a number of new fossil Mammals have become known, and have been identified as the ancestors of the existing Marsupial Mammals, distinguished from them in many cases by the much greater size of the fossil forms.

In addition to the above-mentioned writings, which for the most part treat whole faunas or connected local occurrences, there are many special memoirs of individual orders or families of Mammalia or on questions of Comparative Osteology and Odontology. The masterly works of W. Kowalesky (1874) and certain papers by Cope discuss the variations undergone by the extremities and the dental apparatus of the Ungulates. Cope's ideas have been carried farther by Wortman, Schlosser, and especially by Osborn, who has proposed an odontological nomenclature of the individual elements of the back-teeth applicable to all Mammals.

The occurrence of human fossil remains and of products of human activity, as well as the origin and evolution of the human race and its affinities to the Primates, have been made the subject of a voluminous literature. But since the task of seeking a solution for these problems now belongs to a special branch of science, Anthropology, Palæontology confines itself more and more to the study of fossil floras and faunas.

CHAPTER VI.

STRATIGRAPHICAL GEOLOGY.

The Early Foundations of Stratigraphy.—In the year 1762, Füchsel proposed the term *Formation* for a series of strata accumulated under similar conditions and in immediate succession to one another. The expression was meant to indicate not only the origin, but also a certain horizon in the stratigraphical succession, and the particular geological age of the series. By Werner's use of the term, it was given an essentially petrographical significance, and lost Füchsel's conception of the serial succession of rock-deposits. In Werner's teaching, the rocks of similar petrographical character were united into a formation; thus the sandstones were regarded as a "formation" distinct from the limestones, and the limestones represented a "formation" distinct from shales, porphyries, etc. But as formations of sandstone, limestone, etc., recurred again and again in the rock-succession, Werner's system allowed for this repetition by grouping the different petrographical formations into "suites," and supposing each suite to represent a definite period in the history of sedimentation.

Brongniart and Cuvier, as well as most of their contemporaries in France, associated with the term *Formation* merely the conception of a particular mode of origin and consequent character of the deposit. On the other hand, for a complex group of strata accumulated within a definite geological epoch, the expression *Terrain* was suggested by Bonnard, Brongniart, and Prévost. In the works of De la Beche, the term *Group*, in Murchison's writings the term *System*, is synonymous with Füchsel's conception of *Formation*.

Humboldt followed Werner in giving to the *Formation* chiefly a genetic and petrographical significance, but he assigned also a certain chronological value. He defined the Formations as "Systems of mineralogical accumulations, which

are associated with one another in such a way that they may be regarded as having taken origin simultaneously." Humboldt admitted that fossils were useful in identifying the age of certain rocks, but thought they could not supply a sufficient basis for establishing a chronological succession of the formations and the different horizons in the formation.

In the year 1822, Conybeare[1] and Phillips published a work on the geology of England and Wales, which, although it has a distinct local colouring, gives a fairly complete representation of the geological knowledge of the sedimentary rocks at the time. The two authors applied throughout the work William Smith's principle of determining the age of the rocks upon the evidence of the fossils contained in them. The introduction contains a succinct historical sketch of the progress of geology in Great Britain. The stratigraphical part begins with a short description of the Alluvium and Diluvium, then enters in fuller detail into the consideration of the "Formations above the Chalk,"—the formations that were afterwards grouped as Tertiary. Conybeare and Phillips differentiated the successive horizons in this group, upon the basis of Webster's and Buckland's researches, into four horizons:—

Upper Marine Formation (Crag and Bagshot Sand).
Fresh-water „
London Clay „
Plastic Clay „

Between these and the Oolite formation Conybeare and Phillips distinguished two main sub-divisions in the Cretaceous formation:—

Upper Cretaceous System, comprising the Chalk deposits.
Lower Cretaceous System, comprising Chalk Marl, Greensand, Weald Clay, and ferruginous sand.

The sub-division of the Oolite formation was carried out on the basis of W. Smith's observations. Conybeare and Phillips distinguished four main divisions:—

Upper Oolite System, with (*a*) Purbeck Series, (*b*) Portland Oolite, (*c*) Kimmeridge Clay.
Middle Oolite System, with (*a*) Coral Rag, (*b*) Oxford Clay.

[1] William Daniel Conybeare, born 1787 in Bishopsgate, studied in Oxford, entered the Church and became Dean of Llandaff; died in August 1857.

Lower Oolite System, with (*a*) Cornbrash, (*b*) Forest Marble, (*c*) Stonesfield Slate, (*d*) Great Oolite, (*e*) Lower Oolite, (*f*) Marl Stone.

Lias.

Between the Oolite and the Carboniferous formation, Conybeare and Phillips recognised the formation of the Red Marl and New Red Sandstone, and that of the Magnesian Limestone. No fossils had been found in the Red Marl and Sandstone formation, but Conybeare and Phillips correctly compared the group with the Bunter Sandstone on the Continent. The Magnesian Limestone of Sunderland, Durham, and Northumberland was identified by means of its characteristic fossils as an equivalent of the "Zechstein" and Copper Slate Series on the Continent (cf. p. 36). Conybeare also recognised in the Conglomerates of Devonshire a formation corresponding to the "Red Underlyer" of the Continental deposits. Finally, the Carboniferous formation was very carefully described, and was sub-divided into four groups—Coal Measures, Millstone Grit and Shales, Carboniferous Limestone, and Old Red Sandstone.

This classic work of Conybeare and Phillips demonstrated in convincing manner that only with the assistance of fossils could a secure foundation be obtained for a comparative consideration of the sedimentary rocks, and although their parallelism of the English deposits with those of the Continent is often erroneous, the method which they adopted signified the scientific recognition and marked success of William Smith's reform.

In Germany, after the collapse of Werner's system, geology seemed for a time to make no progress. It was only by slow degrees that the palæontological method could ingratiate itself with geologists. Keferstein's *Tables of Comparative Geognosy* (Halle, 1825) presents a curious combination of Wernerian ideas, Humboldt's teaching, and the influence of the new British methods. "Neptunian Formations," six in all, and "Volcanic Formations," also to the number of six, are arranged in two corresponding columns. The Granite and Syenite are placed lowest in the Volcanic formations as the oldest Volcanic rocks contemporaneous with the gneiss, schist, greywackes, and slates that were comprised in the oldest sedimentary "Formation Suite" by Werner. The "Porphyry" Volcanic formation is regarded as the contemporary of the

Carboniferous formations; the "Augite Porphyry" is the contemporary of the Permo-Triassic and Liassic formations; the "Trachyte" is correlated with the Jurassic and Cretaceous formations; the "Basalt" with the Tertiary deposits; and the Lava with the Diluvial and Alluvial accumulations. The enumeration of the stratigraphical rock-succession undoubtedly shows a considerable advance on the text-books with almost exclusively Wernerian sub-divisions, which had hitherto held the place of authority in Germany.

Ami Boué, in his *Geognostic Sketches in Germany* (1829), describes the series of formations and their distribution in Germany. These sketches give a wonderfully comprehensive view of the stratigraphical relations in Germany itself, and draw a careful comparison between the character of the formations in Germany and their age-equivalents in other parts of Europe. A much clearer insight is given into the leading stratigraphical features of the Alps, Ami Boué's personal knowledge of the rock-succession in other countries enabling him to form broader conceptions regarding different developments or facies of formations belonging to the same geological epoch. But still more important was the new light thrown by Ami Boué upon the distribution of Tertiary deposits in Central Europe. He pointed out that these deposits occur in five well-defined basin-shaped areas: namely, the North-German, Bohemian, Rhineland, Swiss-Bavarian, and Austro-Hungarian depressions. Boué showed that in none of those areas were the deposits identical in character with the deposits of the same age in France and England. The exposition of these relationships is one of the finest contributions to the stratigraphical knowledge of the time, Boué relying almost entirely upon his own independent observations. Boué's penetration is the more remarkable since it was little aided by palæontological data, and Boué was no great believer in the stratigraphical value of fossils.

Alexandre Brongniart was one of the most active Continental pioneers of the application of palæontological methods to the problem presented by geological field-surveying. In 1829 he made the attempt to describe all the rocks composing the earth's crust in chronological order, and to introduce a new nomenclature for the successive horizons of rock, which should be quite independent of lithological features. In his system Brongniart distinguished nine classes of *Terrains*, stating that

he assumes nothing further regarding the rocks comprised in a "Terrain" than that they originated during a definite great geological period. The "Terrains" are then sub-divided in *Formations* or Groups. Each Formation is said to contain rocks that had been formed under similar or almost identical conditions; and the Formations are again divided into Sub-Formations (*Sous-Formations*), each of which is said to comprise a complex of strata conformably succeeding one another, and having the same fossil fauna or flora. The most valuable part of Brongniart's work is the large number of lists enumerating the characteristic fossils in the sub-formations.

The Terrains are classified under two Periods, the *Periode Jovienne*, with the three youngest, and the *Periode Saturnienne*, with the other six Terrains.

D'Omalius d'Halloy partly accepted Brongniart's terminology, partly altered it, but he followed the sub-division and general arrangement of the Terrains. The Belgian geologist was Brongniart's solitary disciple in the literature. In comparison with the contemporary work in Great Britain, Brongniart's stratigraphical system could only be regarded as a retrogressive step.

The excellent *Geological Manual* of De la Beche (London, 1831) followed the example of W. Smith, Conybeare and Phillips, and adopted their terminology and their arrangement of the formations. That De la Beche showed a special interest in the modern and diluvial formations was only what might have been expected in the author of the *Geological Observer.* In his treatment of the "Group above the Chalk," De la Beche made use of the literature on the Tertiary formations of the Paris basin, Italy, Switzerland, and the other Tertiary basins of Europe, but in spite of the rich material in the literature he failed to construct a precise, chronological table of the succession. For the Cretaceous group, the English sub-divisions are taken as a type; in the Oolitic group, De la Beche made only one or two slight alterations on W. Smith's sub-divisions, and, on the basis of the important works of Merian and Thirria, assigned the Jurassic formations of the Swiss and French Jura to their proper position in the stratigraphical succession. De la Beche included in the group of the "Red Sandstone" the whole series of Keuper, Muschelkalk, Bunter Sandstone, Zechstein, Copper Slate, and Red Underlyer. In the Carboniferous formation he embraced very rightly only the

Coal deposits and the Carboniferous Limestone; the Greywacke group included for the most part Werner's "Transitional Series," but a Lower "fossiliferous group" of shales was differentiated to comprise the oldest shales and greywackes in Wales and Brittany. At the base of this fossiliferous formation, De la Beche described the lower unfossiliferous series of strata (schists, gneiss, granulite, etc.), and finally the unfossiliferous eruptive varieties of rock. This text-book by De la Beche had a wide circulation; it was translated by H. von Dechen (1835) into German, and by Brochant de Villiers (1833), in somewhat altered form, into French.

In the year 1833 the third volume of Lyell's *Principles of Geology* appeared, the volume which was afterwards published as an independent work, entitled *The Elements of Geology*. This volume is especially memorable in stratigraphy for its skilful solution of the difficult task of establishing a chronological sub-division of the Tertiary strata, that should apply equally to the occurrences of this series in all the isolated basins of deposition. With the help of P. Deshayes, Lyell proposed the classification that has become permanent in the science.

Several years earlier, in 1829, Desnoyers, in an important treatise, had proved that the different Tertiary basins had not been filled with quite contemporaneous deposits, but that in some of the basins deposition only commenced after others had been partially or wholly silted up with sediments. The Tertiary series could, he said, be naturally sub-divided into an older and a younger group of sediments.

In the following year, 1830, P. Deshayes[1] published the results of his investigations on the resemblances and genetic relations of the Tertiary Molluscs to the existing fauna. No fewer than 2,902 species of Tertiary Conchylia, all derived from known localities and horizons of deposit, were compared with one another and with 4,639 living species. The results

[1] Paul Ger. Deshayes, born 1796 at Nancy, studied medicine in Strasburg and Paris, but never entered into professional practice. He taught privately, and devoted his leisure to zoological and conchological studies. From 1839 to 1842 he lived in Algeria, in order to make special researches on the molluscan fauna of that neighbourhood. After his return, he held private courses of lectures on geology and palæontology, and in 1869 he was appointed Professor of Conchology at the Museum in Paris; died on the 24th May 1896. His splendid collection was acquired by the State, and is exhibited in the School of Mines in Paris.

showed that a number of deposits in the Paris and London basin, in the Belgian and in the Vicentinian basins, contained only about 3 per cent. existing species and 97 per cent. extinct species; and that of 1,400 investigated species, only 42 continue upward into the younger group of Tertiary rocks which comprise the Faluns of Touraine and Aquitania, the deposits of the Vienna and Hungarian basin, of Poland, and the Superga, near Turin. In these localities, 18 per cent. existing species are represented. In the third and youngest subdivision of the Tertiary rocks comprising the sub-Apennine formation of Italy, the marine deposits of Greece, and the Crag of England, there are 52 per cent. existing species. The still younger bivalve banks of Uddewalla, Sicily, Nice, etc., contain 96 per cent. existing species. The complete Tables of Deshayes were published in the year 1833 in Lyell's *Principles of Geology.* It is difficult to tell in how far Lyell was the originator of the researches so brilliantly carried out by Deshayes; the distinguished British geologist had certainly devoted special attention to the Tertiary Molluscan faunas during his early journeys in Italy.

Lyell proposed the names of Eocene, Miocene, and Pliocene for the three sub-divisions of the Tertiary rocks which Deshayes had established, and some time afterwards he suggested that the so-called Diluvial deposits above the Tertiary rocks should be termed "Pleistocene." Lyell's terminology was soon universally adopted in geological literature.

Quite independently of Deshayes and Lyell, H. G. Bronn had been conducting a detailed series of researches on the distribution of the organic remains in the Italian Tertiary rocks, and published his results in tabulated form in the year 1831. The learned Heidelberg palæontologist (cf. foot-note, p. 364) demonstrated as leading principles that the total number of the genera and species in the Tertiary deposits increased in the successive horizons of deposit from the lower to the higher, and that the number of extinct species diminished in each successively younger horizon, while the number of existing species became proportionally greater. Applying these principles as a stratigraphical basis, Bronn sub-divided the Tertiary deposits of Europe into two groups, the older of which corresponds almost exactly with Lyell's "Eocene" formation, while the younger or upper series of Bronn corresponds with Lyell's "Miocene" and "Pliocene" formation.

Deshayes, Lyell, and Bronn had thus verified the importance of comparative study in defining a successive series of palæontological horizons within each larger group of rock-strata. The security of the method, and its community of interest with zoological studies, lent a new fascination to the stratigraphical aspects of geology. The subject promised a good field of research, and attracted some of the most acute intellects of Europe into its service. The part of the geological record which still remained very obscure was the so-called "Transitional" series below the Carboniferous rocks embracing the thick greywacke formation with interbedded shales, slates, conglomerates, and limestone. This group still retained its Wernerian appellation in literature, although many authors had comprised under it some of the "Primitive" rocks in Werner's system (*ante*, p. 58). Continental authors had contributed memoirs on the Harz mountains, on Gothland, the Rhine and Belgian areas of "Transitional" rocks, and had erected stratigraphical sub-divisions of a local value formed chiefly on petrographical characteristics; but no complete sub-division of the immense complex of strata between the crystalline schists and the coal measures had been attempted.

This was the gigantic task which two British geologists, Adam Sedgwick[1] and Roderick Murchison,[2] set themselves

[1] Adam Sedgwick, born on the 22nd March 1785, at Dent in Yorkshire, the son of a clergyman, studied theology and mathematics in Cambridge; in 1809 became an assistant demonstrator at Trinity College, and in 1818 Professor of Geology at the University of Cambridge. In 1822 he began his researches in Cumberland; in 1826 made his first journey with Roderick Murchison to Scotland, and worked for ten years along with Murchison, until the difference of opinion about the Cambrian formation embittered their friendship. Sedgwick was a born teacher; his lectures, full of enthusiasm and relieved by a ready sense of humour, stimulated many of the younger men to devote themselves to geology; he was also the founder of a rich geological museum in Cambridge, whose scientific value was highly eulogised when the Wollaston and Copley medals were conferred on him. Sedgwick died on the 27th January 1873, in Cambridge.

[2] Roderick Impey Murchison, born on the 19th February 1792, at Tarradale in the Scottish Highlands, was trained at Great Marlow for a military career, and was an officer in the Spanish campaign of 1807. He married in 1815 the accomplished daughter of General Hugonin, who encouraged him to follow out his bent for science. After short preparatory studies, Murchison began his literary activity with several memoirs on the geology of Sussex, the north of Scotland, and Arran; he travelled in 1828 with Lyell in France and Upper Italy, and together with Sedgwick made detailed geological studies in the Austrian and Bavarian Alps. In 1831 he began his famous investigations of the Palæozoic deposits in Wales

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[redacted]

to accomplish in the British area, and which was fulfilled in a manner worthy of the noblest traditions of their countryman, William Smith.

In the summer of 1831 the two friends began their investigations in Wales and the neighbouring districts. Sedgwick had already studied the Transitional formations in the Lake District of Cumberland and Westmoreland between 1822 and 1824, and had disentangled the tectonic structure and stratigraphy of this very complicated district, although his sub-division of the formation had been based, in the absence of fossils, merely upon the lithological features and stratigraphical relations. The Cambridge professor in 1831 renewed his study of the same formations in North Wales, in the neighbourhood of Snowdon, and elucidated the tectonic relations of the rocks with admirable skill. Unfortunately the scarcity of fossils made it still impossible for Sedgwick to establish palæontological sub-divisions. Murchison was more fortunate. While his colleague was engaged in the examination of the oldest group of the Transitional series, Murchison began his investigation of the series in descending order from the upper members to the lower. He examined the exposures of Old Red Sandstone and the rocks immediately below it, which occur on the eastern and southern borders of Wales.

Murchison found fossils in abundance, and in a couple of years was able to lay before the Geological Society a complete palæontological sequence in the upper portion of the Transitional formations. At first Murchison had called these higher members examined by him an "Upper fossiliferous greywacke series"; but in the year 1835, in compliance with the strongly-expressed wish of Elie de Beaumont, he proposed the name "Silurian System" as a special designation for the upper members. And as the older members of the Transitional series examined by Sedgwick in Cumberland and North Wales could not be identified with any of the members in the Silurian system of Murchison, the term of "Cambrian Series" was

and he afterwards continued his researches in Devonshire, Germany, Belgium, and Russia. In 1855 Murchison succeeded De la Beche as Director of the Geological Survey of Great Britain. Murchison was one of the founders of the British Association, twice President of the Geological Society, and for many years President of the Geographical Society; he was also a recipient of the Wollaston medal; in 1866 he was created a baronet. Throughout his career Murchison took a distinguished position in London society. He died on the 22nd October 1871.

proposed by Sedgwick in 1836 for these older members, and this term was accepted by Murchison.

In the year 1839 Murchison published his great work *The Silurian System*, wherein the results of his researches extending over six years were admirably elucidated. After a short statement regarding the younger geological formations, and a more detailed account of the English Carboniferous formation, the Mountain Limestone, and the Old Red Sandstone, Murchison passes to the special description of the Silurian system in South Wales and the adjoining counties of England. With great accuracy he depicts the stratigraphical relations, the lithological characters of the rocks, the contents of fossils and minerals, and the occurrences of volcanic rocks. A special palæontological part with twenty-seven quarto plates is devoted to the description of the characteristic fossils by L. Agassiz, Sowerby, and Lonsdale. Numerous coloured sections help to demonstrate the tectonic relations of the district.

Murchison distinguishes three chief divisions in the Silurian system—

Upper Silurian, comprising the Ludlow Rocks and Wenlock Limestone.
Lower Silurian, comprising the Caradoc Sandstone and Llandeilo Flags.
Cambrian.

Murchison found it impossible at the time to fix a definite palæontological horizon as the lower limit of the Silurian system, and Sedgwick also could not assign any palæontological or other feature which would determine the upper limit of the Cambrian series. Nevertheless, the recognition of the Silurian and Cambrian systems was one of the most important advances that have been made in stratigraphy.

There still remained, however, a thick group of strata in the Wernerian "Transitional Series" which could not be allotted to either of the newly-defined systems. De la Beche had worked with unrelaxing energy for several years at the geological investigation of Devonshire and Cornwall, and in 1839 had reproduced his results on an excellent geological map of this district. He had separated a series of plant-bearing shales from the true greywacke strata (Killas Greywacke) and applied to them the name Carbonaceous *series* (now "Culm Shales"), but he thought the latter was in

part older than the greywacke beds. In the year 1836, Murchison and Sedgwick proved that the shales belong to the Carboniferous formation and repose upon the true greywacke series with interbedded conglomerates, shales, and fossiliferous limestone. The whole complex of strata is so strongly compressed and folded, and the rocks show such striking metamorphic features, that Murchison and Sedgwick both were of opinion they must be of Cambrian age. But Lonsdale, to whom the fossils were entrusted for examination in 1837, expressed his conviction that the Killas greywacke complex must be younger than the Silurian system and older than the Carboniferous system. Although at first a little incredulous, after a careful revision of their sections, the two geologists accepted Lonsdale's conclusion, and together wrote a large memoir (1839) on the newly-identified system of strata, which they termed the "Devonian," between the upper Silurian and lower Carboniferous. In addition to the greywacke series in Devon and Cornwall, they assigned to the Devonian system the Old Red Sandstone in Scotland, whose distribution, thickness, divisions, and fossils had been the subject of their earlier memoir published in 1828.

Many doubts were cast upon the independence of this new system, and Murchison and Sedgwick resolved to test their results by means of comparative researches in the Continental districts where the Wernerian "Transitional Series" had been chiefly studied. The two friends travelled in the summer of 1839 through the Rhine district, Westphalia, the Harz, Nassau, Thuringia, the Fichtel mountains; in the companionship of De Verneuil, they also travelled in Belgium and the neighbourhood of Boulogne. In 1842, Murchison and Sedgwick published a memoir in which they tried to show that a great portion of the shales and limestones, as well as the sandstones, greywackes, and conglomerates exposed in the Rhineland belonged to the Devonian and Silurian system, and that in the Fichtel mountains Devonian deposits were present, but no Silurian. These results were partially erroneous with regard to the Silurian division, since the whole of the lower greywacke series in the Rhine district was said to be Silurian, and the Silurian deposits in the Fichtel mountains were entirely overlooked. Still, the investigations of the two British geologists proved incontestably that there lay between the Carboniferous system and the

older greywacke in Germany and Belgium a complex of strata sometimes highly fossiliferous, and the indubitable equivalent in age of the Devonian system in Great Britain.

The fossil remains from the Palæozoic rocks of Cornwall, Devon, and West Somerset were described by Sowerby (1837), and were again worked out by John Phillips in 1841. Phillips[1] revised very carefully and established more securely the palæontological sequence of Devonian sub-divisions which had been proposed by De la Beche, Murchison and Sedgwick, and Lonsdale. In their earlier papers, Murchison and Sedgwick had sometimes designated the Silurian deposits as Palæozoic, and the Cambrian as Protozoic. Phillips suggested (1841) that the name *Palæozoic* should be applied to all the strata of the "Transitional" series (the Cambrian, Silurian, and Devonian of British geologists), together with the Carboniferous system and the Zechstein; that the name *Mesozoic* should be applied to the Secondary deposits, and *Cainozoic* to the Tertiary. This nomenclature rapidly found favour, and is now universally accepted.

Until about the year 1840, geologists had derived their information regarding the Cambrian, Silurian, and Devonian deposits only from regions in which the strata show great tectonic disturbances and complicated relations. The news that these rocks occurred in Russia over wide tracts of territory, and in an almost horizontal position, aroused the interest of Murchison to such a degree that in 1840 he undertook a journey in company with Verneuil to the Baltic Sea Provinces. In the following year Murchison made that important expedition to the Ural mountains, whose outstanding result was not only the proof of the wide extension of Silurian and Devonian deposits in Russia, but also the erection of the "Permian System."

His continued researches on the Palæozoic formations had led Murchison to conclude that the Cambrian deposits examined by Sedgwick in North Wales contained no fossils

[1] John Phillips, born 1800 at Marden in Wiltshire, was the nephew of William Smith, and was guided by this great master into geological studies. In the year 1824 he was commissioned to arrange the museum of York, and he was for ten years occupied in carrying out similar commissions in other towns, finally in London, Dublin, and Oxford. In 1834 he was appointed Professor of Geology at King's College in London, in 1844 Professor of Geology in Dublin, and in 1856 he succeeded Buckland as Professor of Geology in Oxford. He died in April 1874.

different from those of the Lower Silurian, and that the Cambrian system was identical with the Lower Silurian. Murchison made known this opinion for the first time in a Presidential Address which he delivered at the Geological Society. Sedgwick was deeply hurt, and immediately began (1842 and 1843) a new investigation of Wales, in which he was assisted by the palæontologist Salter. In 1852, he upheld the independence of the Cambrian series, contending that under the Llandeilo of Murchison, which he recognised from the identity in the fossils to be contemporaneous with the Bala Beds and designated *Upper Cambrian*, there was another complex of strata about 10,000 feet in thickness. In this complex, Sedgwick distinguished two main divisions, the Festiniog and Bangor groups, with the subordinate members Arenig flags and shales, Tremadoc slates, Lingula flags, Harlech grits and shales, and Llanberis shales.

Murchison was not persuaded by Sedgwick's results, and demanded a palæontological foundation for the Cambrian system. In the year 1854, a somewhat shortened and completely re-modelled edition of the *Silurian System* appeared in octavo form, under the title *Siluria*. Murchison in this edition treated the "Cambrian Series" merely as a local facies of the Lower Silurian division, and set aside its claims to be regarded as an independent system. Murchison's *Siluria* begins with the oldest fossiliferous deposits in Wales (the Longmynd group) and provides in ascending order a detailed description of the Silurian, Devonian, Carboniferous, and Permian systems in England, concluding with a comparative account of the corresponding formations in the other parts of Europe and North America.

The members of the Geological Survey, to whom the investigation of Wales was entrusted, followed the views of Murchison, the Cambrian system disappeared from the official maps, and the colour for Silurian rocks was carried over the whole of the area previously allotted to the Cambrian system. Sedgwick, embittered by the want of recognition for his Cambrian system, published (1851-55) a large work on the divisions and the fossils of the British Palæozoic deposits, and protested in strong terms against the views held by his former friend and fellow-worker Murchison. He insisted upon the independence of the Cambrian system, and wished to limit the Silurian system to the Ludlow and Wenlock

groups, referring all the deposits from the Caradoc series downwards to the Cambrian series. The high-spirited Cambridge Professor could, however, make no impression upon his contemporaries against his influential opponent, who in 1855 became the General Director of the Geological Survey. Indeed, the Council of the Geological Society in 1852 placed themselves openly on Murchison's side by passing a resolution to decline on principle any communication made by Sedgwick on the classification and nomenclature of the older Palæozoic deposits.

Nevertheless Sedgwick adhered to his own classification, and published a historical review of his researches on the Palæozoic rocks of Great Britain, which appeared as an introduction to an illustrated catalogue of Cambrian and Silurian fossils drawn up by J. W. Salter. Sedgwick, in this last scientific exposition of his views,—for he died in the year of its publication (1873),—emphasised once again the independence of the Cambrian deposits, showed that the Cambrian system contained characteristic fossils, distinct from those of the Silurian system, and that it was consequently founded upon secure palæontological data. In the end Sedgwick has been found right. The Cambrian system, although with a certain modification of its limits, is now recognised as an independent geological system represented throughout the whole earth.

Special Stratigraphy.—The general framework of stratigraphical teaching had thus been constructed by the works of Lyell, Deshayes, and Bronn on Cainozoic rocks, by those of Smith, Conybeare, and Phillips on Mesozoic rocks, and those of Sedgwick and Murchison on Palæozoic rocks. It was left for younger generations of geologists to work out the finer details and more accurate division of the successive formations. This task was willingly undertaken by a thousand diligent hands, not only in Europe but throughout the world. Little change has been made on the limits of the main divisions (formations or systems) of the stratigraphical framework, but the work of determining palæontological sequences in greater and greater detail is still in full progress, and the recognition of the minor stratigraphical members within the formations varies from time to time with the increasing knowledge and understanding of the geological structure of the earth's crust in Europe and other parts of the world.

A. *Archæan and Pre-Cambrian Rocks.*—The great complex of gneiss and crystalline schists which forms the basement of the oldest fossiliferous sedimentary rocks, and had always since Werner's time been divided according to lithological characters, was imbued with new interest when, in 1854, William Logan reported the presence of organic remains in limestone interbedded with the ancient gneiss of Canada. The *Eozoon Canadense* was regarded by Sir J. W. Dawson and W. B. Carpenter as a foraminiferal genus, and the supposed complex of Archæan schists and gneiss was accordingly placed in the series of sedimentary formations. Logan (1863) differentiated in Canada an older Laurentian gneiss formation and a younger Huronian formation resting upon it, and chiefly composed of mica schist and phyllite. Gümbel proposed a similar sub-division of the basement rocks in the area of the "Bavarian Forest." These divisions have not, however, been verified by subsequent researches; in some parts of North America it has been demonstrated that the Laurentian granitoid and gneissose masses are continuous with dykes and veins in the schists and phyllites, and these intrusions must be younger than the Huronian series into which they have forced their way.

The organic nature of the "Eozoon" was afterwards discredited by King, Rowney, and Moebius (cf. p. 386), but the adherents of the theory of descent argued the strong probability of the occurrence of organic remains in these ancient pre-Cambrian rocks. And now and again other evidences of organic life are found in the ancient schists and phyllites, *e.g.*, worm-burrows, sponge spicules, and traces of Algæ or Protozoa. Geologists have succeeded in areas where there has been a relatively small degree of metamorphism in determining a general chronological succession in the Archæan rocks. But in countries of repeated crust-disturbances and great regional metamorphism, the task is much more difficult and complicated, although it has frequently been attempted. Hicks (1877) distinguished in Wales and Scotland four divisions, *Lewisian*, *Dimetian*, *Arvonian*, and *Pebidian;* A. Nathorst, in Sweden, differentiated three formations, a Lower *Dal* formation, a Middle *Almesakra* formation, and an Upper *Wisingsö* formation.

In the year 1892, Van Hise published an exhaustive account of the pre-Cambrian formation in North America,

which he sub-divided into two chief groups: the younger or *Algonkian* (a term introduced by Walcott from the name of an Indian race) comprises the clastic or crystalline rocks immediately below the Cambrian system, while the older or *Archæan* group comprises the wholly crystalline and foliated basement complex of rocks.

The pre-Cambrian phyllites, schists, and conglomerates of Brittany have been subjected to a close examination by Barrois (1883-94), who has greatly advanced the knowledge of the stratigraphy of that complicated area. Barrois discovered organic remains in the quartzites, and Cayeux identified them as Radiolaria and sponges. Rauff, on the other hand, regards these supposed fossil remains merely as mineral structures.

Alpine geologists have, in the course of detailed geological surveys, frequently been able to prove that gneissose and schistose areas of rocks which used to be regarded as pre-Cambrian represent metamorphosed portions of the younger formations. Even Cainozoic rocks have undergone complete metamorphism in highly-disturbed Alpine regions.

The insuperable difficulty with which geologists have to contend in their attempts to unravel the complicated stratigraphical relations of metamorphic rocks is that, in virtue of the changes they have undergone, any fossil remains which might originally have been contained in them have been nearly all altered beyond sure recognition. Then there is the other difficulty that not only the sedimentary series, but also the plutonic igneous masses and injected igneous rocks, when they undergo strong crust pressures, may be converted into foliated metamorphic rocks. Hence the only means of arriving at a just appreciation of the age and relationships of the metamorphic rocks is, first, by careful cartographical survey and comparison of the stratigraphical relations subsisting between the several members of a metamorphic series and the sedimentary unaltered rocks; and second, by finer microscopic investigation of rock-specimens, taken from all grades of altered and unaltered rocks whose relations in the field have been fully investigated.

Only after prolonged researches can geology hope to determine how much of the crystalline metamorphic rocks really belongs to an Archæan and pre-Cambrian basement series, and how much is of later sedimentary or igneous origin.

B. *Cambrian and Silurian System.*—Almost contemporaneously with Sedgwick's and Murchison's famous researches in European areas, North American geologists were extending the knowledge of the vast tracts of older Palæozoic rocks in North America.

Between 1818 and 1832, A. Eaton published a series of pamphlets wherein he erroneously compared the sedimentary deposits in the east of the United States with the Mesozoic formations in Europe. Vanuxem in 1829 proved that the deposits in the east of the United States belonged exclusively to the "Transitional" series. In the following decade geological survey departments were established in several of the eastern and southern states, after the model of the British Geological Survey, and this gave a strong impulse to the development of Geology and Palæontology in North America. In New York State, the official surveys were commenced in the year 1836, and the survey department was divided into four independent sections. The South-Western Section was placed under the direction of Lieutenant Mather, the North-Eastern under Professor Ebenezer Emmons, the Middle Section under Conrad, and the Western Section under Vanuxem, who had been trained in Paris. In 1837 Conrad retired from active field-work on account of his health, and devoted himself to palæontological work. Vanuxem replaced him as director of the Middle Section, and J. Hall was given the Western Section.

Emmons, in 1842, published the general results obtained in the North-Eastern district, which in a large measure is composed of crystalline plutonic masses, gneiss, and crystalline schists. Among the sedimentary deposits, the "transitional" series has the widest extension. Emmons applied local names to the several divisions, calling the main complex of Palæozoic rock the "New York System," and sub-dividing it into four members irrespective of European classificatory groups—1, Champlain; 2, Ontario; 3, Helderberg; and 4, Erie Group. According to Emmons, the New York system was succeeded by the Old Red system, and rested upon the Taconic system. The latter reposed on the crystalline schists, and was said to consist of an unfossiliferous complex of slates, flagstones, limestone, and quartzite attaining a thickness of about 25,000 feet. The unfossiliferous complex was strongly contorted and disturbed, whereas the deposits of the New York system were almost horizontal.

The report of Vanuxem, published in the same year (1842), took the same general standpoint as that of Emmons, but Vanuxem extended the name of New York system so as to include the Old Red Sandstone. Mather (1843) in his official report protested against the independence of the Taconic system, contending that it was a strongly metamorphosed representative of the Champlain group. In this view, Mather was supported by Hitchcock, Rogers, Dana, and J. Hall.[1] The report by Hall (1843) gave an admirable exposition of the three upper divisions of the New York system. The subordinate groups proposed by Vanuxem and Conrad were for the most part accepted, and a few additional groups were introduced, so that the New York system (exclusive of the Old Red) was now sub-divided into twenty-nine groups.

Hall made a comparison between the palæontological sequence in these groups and the sequence that had been worked out by Murchison and Sedgwick. For the five lower groups (from the Potsdam sandstone to the Trenton limestone) Hall could adduce no British equivalent; the Utica slates were compared with the Llandeilo slates (Lower Silurian) of Murchison; the groups from the Hudson river beds and the Clinton group were said to be equivalent with the Caradoc or Bala shales and flagstones; the groups from the Niagara beds to the Corniferous-Limestone group were compared with the Wenlock shales and limestones; and the strata from the Marcellus and Hamilton groups to the Chemung group were regarded as the equivalent both of the uppermost or Ludlow division of the Silurian system and of the Devonian system. Each of Hall's groups is very accurately characterised according to stratigraphical, lithological, and palæontological features. And as the strata in the area examined by Vanuxem and Hall follow almost everywhere in horizontal or gently inclined position without any appreciable tectonic disturbances, the sub-divisions erected by these geologists have undergone little subsequent modification. Some time later, Hall described in a series of handsomely-illustrated volumes the Palæozoic

[1] James Hall, born on the 12th September 1811, at Hingham in Massachusetts, received his scientific education at the Polytechnic School of Troy; in 1836, entered the Geological Survey Department of New York State, and was afterwards Director of the Natural History Museum in Albany. He died in his eighty-seventh year (1898) in Albany.

fossils, not only of State New York but also of a large portion of North America.

Contemporaneously with the investigations in New York State, the two brothers Rogers (cf. p. 304) were directing and participating in the survey of Pennsylvania and Virginia. There also it was found that the Palæozoic deposits were exposed over wide areas, and the stratigraphical succession was determined. But Edouard de Verneuil, who travelled in North America in the year 1846, was the first to institute a more detailed comparison between the relations of the American and the European "Transitional" formation. Verneuil drew up a table of the parallel palæontological horizons in the two regions, and established a line of division between the Silurian and the Devonian systems in North America. Some time later, J. J. Bigsby published a very exhaustive and lucid synopsis of the New York system in comparison with the parallel formations of Europe (*Quart. Journ. Geol. Soc.*, 1858).

The Taconic system continued to be ignored by the leading geological authorities in North America, notwithstanding that Emmons published a very able book on the subject in 1844, affording strong evidences of the wide extension of the Taconic system in the New England States, and its independence of the Champlain group. In Washington County, moreover, the first Taconic fossils were discovered (two Trilobite species, Graptolites and Nereites), and proved to be quite different from any known Palæozoic forms. Further discoveries of fossils followed, and these were described and figured by Emmons; he also traced the Taconic system in Pennsylvania, Virginia, and Georgia. But as Hall, Dana, Logan, and other geologists continued obstinate in their view regarding the identity of the Taconic and the Champlain groups, a hot polemical discussion ensued and dragged itself through the following decades.

In the year 1860, the European authorities Barrande and Marcou began to take part in this discussion among the American geologists, supporting Emmons in his view that the Taconic system was an independent formation containing a primordial fauna. Marcou wrote a series of papers, wherein he advocated that the term "Taconic System" should replace the disputed name of "Cambrian System" for the primordial group of rocks; that the name of *Cambrian System* be

retained for the Lower Silurian of Murchison; and the term *Silurian System* be limited to the Wenlock and Ludlow groups. Marcou justly pointed out that all the fossils ascribed by Sedgwick and M'Coy as characteristic of Sedgwick's Upper Cambrian (Bala) series were Lower Silurian fossils, whereas distinctive fossil-types had been found by Emmons in the "Taconic System," hence the latter term ought to be applied generally to primordial rocks containing that fauna. But Barrande had observed in 1851 in the British Survey Collection a fossil Trilobite of primordial age, and Salter afterwards discovered the localities in Wales whence certain pre-Silurian fossils were derived. The "Lingula" flags and shales of St. David's proved richly fossiliferous, and after these had been described by Salter and Hicks (1868), there could no longer be any question that there existed a distinctive fauna in Sedgwick's original "Cambrian Series."

It is largely due to Lyell's example that the name of "Cambrian" was retained in the text-books, at first usually as a sub-division of the Silurian system, but finally as a system of equal rank with the Silurian.

The Cambridge School continued until recently to teach, in accordance with Sedgwick's views, that the limit between the Cambrian and Silurian systems was above the Bala beds. Lyell, in his *Elements of Geology*, limited the Cambrian system to the lower and middle members of Sedgwick's system, beginning with the Longmynd strata and ascending to the Tremadoc slates; and in 1888, at the International Congress in London, this limit was sanctioned and has since been almost universally adopted.

In the year 1879, Lapworth proposed the designation *Ordovician* for the complex of strata which had been variously termed Lower Silurian or Upper Cambrian. Lapworth's detailed research and intimate knowledge of the group led him to the opinion that it should be ranked as an independent system, as it was distinguished from the rocks above and below, not only by the occurrence of distinct fossil types but likewise by the intercalation of lavas, tuffs, and ashes amidst its sedimentary series. The Ordovician system has been subdivided by Lapworth upon palæontological grounds into a Lower Ordovician or Arenig series, a Middle Ordovician or Llandeilo series, and an Upper Ordovician or Bala series.

A renewed investigation of Emmons' district in the United

States was undertaken by C. D. Walcott, whose results showed that, as Emmons had contended, the Taconic system was a well-developed complex of strata below the Potsdam Sandstone, and containing an exclusively primordial fauna.

Walcott then went to survey in the Far West, where Gilbert and Hague had described Cambrian deposits in the Eureka district of Nevada. In several important publications (1884-90) Walcott has elucidated with full details the extension, lithological character, stratigraphical relations, subdivisions, and fauna of the Cambrian system in North America.

The "Transitional Rocks" in the vicinity of Prague had very early attracted the attention of collectors and geologists on account of the profuse abundance of fossils, and these had been made the subject of palæontological memoirs by Born, Count Sternberg, Beyrich, Emmrich, Corda, and others. The first geological work of note in this district was accomplished by Joachim Barrande.[1] By his life's devotion to the cause of research, this quiet, retiring geologist made Bohemia classic ground for the study of the oldest fossiliferous formations.

In the year 1846 Barrande published a short account of the Bohemian Silurian basin. He described its structure as consisting of a number of stages (*Étages*), which he designated by the letters A to G. The succession, stratigraphical position, and the fossil contents were determined with the utmost precision, and a comparison was instituted between the Bohemian

[1] Joachim Barrande, born on the 11th August 1799, in Sangues (Haute Loire), was educated in Paris, and intended to be an engineer, but left Paris in 1820 with the banished Royal Family of France, following them at first to England and Scotland, and then to Bohemia. In the year 1831 he became tutor to Prince Henry of Chambord, with whom he continued in intimate relations all his life as the administrator of the Prince's property. After relinquishing his post of tutor, Barrande devoted himself to the geological and palæontological investigation of the Silurian basis of Bohemia. He acquired an unrivalled collection of fossils: no trouble was spared to secure the spoils of the rocks: quarries were opened, workmen engaged, collectors kept constantly occupied and carefully trained, until Barrande's collection in Prague became the admiration of the geological world. His private life was uneventful. He lived quietly and simply, and the only interruption to his monotonous existence was when he undertook some longer journey for the sake of comparing his fossils and his stratigraphical results. He had considerable private means, which he almost entirely sacrificed to his scientific requirements. He died in October 1883, at Count Chambord's estate of Frohsdorf. Barrande bequeathed his valuable fossil collection to the Bohemian Museum.

and the British Silurian deposits. This preliminary work was followed in the year 1852 by the first volume of his great work on the Silurian system in Bohemia, a work which stands almost unrivalled in palæontological literature. From the year 1852 to the year of his death, 1883, Barrande continued the work and produced twenty-two thick quarto volumes with 1,160 wonderfully prepared plates depicting the complete fauna of the Silurian basin in Bohemia. He bequeathed means in order that the work should be continued to the end.

A geological Introduction in the first volume gives a very careful description of the geology of the area. According to Barrande, the stages A and B are "Azoic," and comprise at the base crystalline schists reposing on granite and gneiss, and above the schists, unfossiliferous greywackes, slates, and shales. Stage C contains the oldest (Cambrian) "Primordial fauna," wherein peculiar Trilobite genera predominate. Stage D contains the second distinct fauna, the equivalent of the Lower Silurian fauna in the Llandeilo and Caradoc series of Wales, the Champlain group of North America, the Orthoceras Limestone of Sweden and Esthland.

While these horizons, A to D, are chiefly greywackes and shales, the higher stages, E to G, are pre-eminently calcareous. Stage E is distinguished by an exceptionally rich fauna, identical with the Wenlock fauna in the British area. Stages F and G are calcareous, stage H comprises soft shales; in these three stages Cephalopod and fish remains are the most frequent fossils. For this fauna Barrande could not find any equivalent in the palæontological sequence of the British Silurian deposits, but he assigned the whole complex E to H to Upper Silurian, and regarded it as a third distinct fauna in the palæontological development.

While Barrande recognised the fundamental agreement between the Silurian horizons determined by him in Bohemia and those already observed in other areas, he remarked on the occurrence of what appeared to be in a measure antecedent "Colonies" of organisms. He found that not infrequently rock-layers containing accumulations of organic types like those of the next higher stage were imbedded in the lower stage; and Barrande explained these "Colonies" by the influx of organisms from certain neighbouring districts in which the fauna had already reached another phase of development.

Barrande's explanation of the "Colonies" was contested by

several geologists, amongst others by Krejci, Lipold, Marr, Lapworth, and a controversy began which continued from 1859 to 1881. The contention of Barrande's opponents was that the colonies had been brought into their apparently paradoxical position by tectonic disturbances of the rocks, whereby certain layers of rock had been sliced and fragmented, and slices of them had been carried into new positions during the crust-movements. Several geologists differed from Barrande about the age which he had ascribed to some of the Bohemian deposits. Marr thought the Azoic stage B of Barrande represented a Cambrian deposit, and Emmanuel Kayser, judging from his own study of the oldest Devonian deposits in the Harz mountains, thought Barrande's stages F, G, and H were not of Upper Silurian age, but belonged to the Devonian system. The Harz fossils, which had been described by Beyrich and Lossen as a "Hercynian stage," closely resembled these fossils in the upper horizons of the Silurian series in Bohemia, and Kayser removed this fauna altogether from the Silurian sequence and described it as Lowest Devonian. Many of the best authorities on Palæozoic faunas have subsequently corroborated Kayser regarding the Devonian type of the fauna in Barrande's higher stages.

The Silurian system in Sweden was sub-divided palæontologically by Angelin in 1854 into eight groups, the lowest of which he called Regio I. Fucoidarum, and the succeeding seven stages also received distinctive names according to the typical Trilobite genus. All the Trilobite genera occurring in Sweden were described in Angelin's works (1852 and 1854). The more recent memoirs by Lindström, Linnarson, Nathorst, Tullberg, and Holm have supplemented and improved Angelin's researches.

The Norwegian Palæozoic deposits, described in the early years of the nineteenth century by Leopold von Buch, as well as by Hausmann and Keilhau, were revised by Kjerulf (1855-57) and arranged in palæontological sequence after the model of the British "Silurian" district. Newer memoirs have been contributed by Broegger (1882) and Kiär (1897).

The Palæozoic deposits in the Baltic Sea provinces of Russia were first examined by Strangways (1819), and were made the subject of special researches by Pander and Kutorga. Murchison recognised Silurian and Devonian strata during his visit to that area, and Pander afterwards gave excellent descriptions of

the "Conodonts" in the Cambrian glauconitic sands and the fish remains in the Old Red Sandstone of Livland. F. Schmidt wrote a monograph of the Silurian Trilobites in this area, and afterwards contributed a masterly exposition of the Silurian rocks in the Baltic area, dividing them into a palæontological sequence which is unsurpassed in the accuracy of its detail (1881-94). Several important memoirs by Stache have demonstrated the presence of Silurian deposits in the Alps, with much wider extension than had previously been surmised.

C. *Devonian System.*—While the controversy about the Cambrian and Silurian systems was still engaging the attention of British geologists, the Continental geologists were applying themselves with vigour to the elucidation of the "Transitional Rocks" in accordance with the new insight which Murchison's writings had shed upon the Palæozoic succession. Friedrich Roemer endeavoured to arrive at some clearer comprehension of the stratigraphical relations in the Harz mountains by a strict palæontological method. In 1843 he published a monograph on the fossils of the Harz mountains. Beginning his observations at the north-western area of the Harz, he explained the Iberg limestone, the Rammelsberg shales, and succeeding strata as Devonian; the Harzburg and Osterode greenstone, together with the surrounding strata and the limestone mass of Elbingerode, as Upper Silurian; the adjoining strata on the east and as far as Andreasberg as Lower Silurian; and the whole of the mountain-system farther east as Cambrian.

Roemer added in subsequent memoirs several valuable contributions to the palæontological data of the Harz, and verified his general statement of the stratigraphy by further details.

As early as 1837, Beyrich had published a number of observations on the fossils of the Eifel, Paffrath, and Nassau limestone. He pointed out their differences from those of the Carboniferous limestone, and showed that the larger portion of the greywacke in the Rhine provinces is older than the limestone of the Eifel and in Nassau, but that above the Nassau limestone there is a thick development of greywackes and slates with Posidonomya Becheri, whose fossils agree with those of the Upper quartz schists in the Liége province.

The Palæozoic formations of the Rhineland were made the subject of an important monograph by Ferdinand Roemer in 1844. This geologist divided the "Transitional Series" into

two main groups: (1) Older argillaceous and arenaceous greywacke; (2) younger calcareous formations. Whereas Murchison, Sedgwick, and Dumont had regarded the older greywacke complex as Silurian, Roemer referred it to the Devonian epoch and identified it with the Terrain Ardoisier and the lowest division of the Terrain Anthraxifère of Dumont. The fossiliferous limestones of the Eifel, Aachen, Bensberg, Elberfeld, and adjacent areas were identified by Roemer with the *lower* limestone group of the Terrain Anthraxifère, and the limestones in Devonshire and Cornwall. He distinguished as an *upper* member of the group Anthraxifère certain fine shales and greywackes (Lenne shales), between Elberfeld and the Sieg and from Iserlohn to Waldeck, which Murchison had referred to the Silurian.

The Palæozoic formations in Nassau, which Murchison and Sedgwick had ascribed to Silurian and Devonian epochs, were afterwards determined by Beyrich and Roemer to be exclusively Devonian. The brothers Guido and Fridolin von Sandberger made a special study of the district, and in 1847 comprised the strata under the term "Rhenish System." They subdivided the system into three groups—a lower complex of greywacke, Taunus shales, and Wissenbach slates; a middle complex of Stringocephalus limestone, dolomite, and Cypridina shales; an upper complex of Posidonomya shales. The fossils of the Rhenish system were admirably described by the brothers Sandberger in a monograph published from 1850 to 1856.

The works contributed by Dumont and Gosselet on the Palæozoic rocks in Belgium provided a thorough groundwork of research in that area. Dumont in 1848 sub-divided the Terrain Ardennais into three groups—Devillien, Revinien, and Salmien; similarly, the Terrain Rhénan into three groups—Gedinnien, Coblentzien, and Ahrien; and the Terrain Anthraxifère above the Terrain Rhénan into three groups—Eifelien, Condrusien, and Houiller. Dumont took little trouble to draw a comparison between these sub-divisions which he erected for the Belgian area and the palæontological groups which had been determined in other countries. He was strongly of opinion that the same fauna never extends over the whole earth, that there had in all epochs been definite geographical kingdoms of plants and animals, and that consequently the fossil contents of rocks could only be used with extreme

caution as a basis of establishing a parallel between rocks in distant areas.

Although Dumont's classification was based wholly upon the characters displayed by the succession in Belgium, it is nevertheless excellently arranged both stratigraphically and lithologically. De Koninck and Murchison afterwards tried to bring his classification into harmony with that of Great Britain and the neighbouring districts of Germany. They relegated the whole of the Terrain Ardennais as well as the Gedinnien group into the Silurian system, and the Coblentzien, Ahrien, Eifelien, and the lower part of the Condrusien, into the Devonian system. Subsequently, Gosselet has carried out a series of studies extending over thirty years on the Palæozoic deposits of Belgium and the Ardennes, and has elucidated the palæontological and stratigraphical relations of the area with admirable care and accuracy.

The Devonian deposits in Brittany and the lower Loire district have been examined by Barrois and Oehlert, while the richly fossiliferous neighbourhood of Cabrières, near Montpellier, has been the subject of several able palæontological monographs by Fournet, Koenen, Frech, De Rouville, and others. The Spanish Devonian deposits have been described by Verneuil, Casiano da Prado, Schulz, and Barrois; while the Devonian occurrences in the eastern Alps have been elucidated by Hoernes, Benecke, and Frech.

D. *Carboniferous System.*—Less difficulty is offered in the classification of the Carboniferous system than in that of the three oldest Palæozoic systems of which Frech has given an exhaustive account in the *Lethæa Palæozoica* (1897). As far back as 1808, D'Omalius d'Halloy comprised the Belgian Carboniferous limestone as a lower group, and the sandstones, shales, and seams as an upper group under the name of *Terrain bituminifère* or *Houiller.* In 1822 Conybeare and Phillips included Carboniferous limestones, the millstone grit and coal measures in the Carboniferous system, but they also placed in it the Old Red Sandstone as a lower sub-division. Murchison and Sedgwick in 1839 transferred the Old Red Sandstone into the Devonian, and recognised in the so-called Culm shales of Devonshire, and in the shales with Posidonomya Becheri in Germany, an arenaceous and argillaceous littoral equivalent of the Carboniferous limestone. The sub-division

of the Carboniferous system into two main groups, in the way that had been proposed by D'Omalius d'Halloy, was almost universally accepted, and on the suggestion of Dechen the upper group was very often called the *Productive Coal-formation.*

With the fauna and palæontological sub-division of the Carboniferous limestone De Koninck occupied himself for more than fifty years. His monographs of the fossil fauna of the Belgian Carboniferous limestone (1842-44), together with MacCoy's work (1844) on the fossils of the Irish Carboniferous limestone, and the somewhat older monograph by J. Phillips (1836) on the Yorkshire Carboniferous limestone, are still the basis of all European research on the faunas of the Carboniferous limestone. De Koninck began a revision of the Belgian fauna (1878-88), but unfortunately this handsomely illustrated work was not completed. In his first monograph De Koninck drew attention to the difference of the faunas at Tournay and Visé, and thought it might be explained on the assumption that they had belonged to two separate basins of deposition. Afterwards he ascribed the limestone of Visé to a slightly earlier period than that of Tournay, whereas Dumont had in 1830 supposed the strata of Tournay to be the older group.

Gosselet in 1860 distinguished three divisions of the limestone: a Lower group, with *Spirifer Tornacensis* as the leading fossil type; a Middle group, with *Spirifer cuspidatus* and *Goniatites sphæroidalis* as the typical fossils; and an Upper group, with *Productus giganteus* and *undatus* as the typical fossils. The palæontological researches of Dupont (1865-71) have confirmed Dumont's view regarding the relative age of the Carboniferous limestone at Visé and at Tournay, showing that the Tournay limestone is the older.

In England, Phillips had sub-divided the Carboniferous limestone of Yorkshire into three groups: (*a*) a Lower series of *Limestone Shales or Sandstones;* (*b*) a Middle series, represented by the *Mountain Limestone*, 2000 feet thick, and containing a rich marine fauna; and (*c*) an Upper series, called the *Yoredale Beds* of limestones, shales and sandstones, and occasional local coal-seams. In the Harz, in Thuringia, in the Fichtel mountains, the Sudeten mountains, and in the Rhine provinces, the Carboniferous limestone division is almost wholly represented by the mixed Culm facies of shales, greywackes, flagstones, and thin beds of limestone.

In the Eastern Alps true Carboniferous limestone was determined in Carinthia by Buch in 1824, but only received the vague name of "Transitional Limestone." De Koninck described the fauna of this limestone in 1873. In the Gail Valley and other localities of the Carnic Alps, the massive limestone is succeeded by dark shales and thin beds of limestone, wherein Tietze and Stache (1872) demonstrated the presence of fossil Foraminifera (Fusulina) in great abundance. The significance of this discovery was not fully realised until a few years later, when it was found that in Russia the true Carboniferous limestone with *Productus giganteus* is succeeded in the Moscow basin by limestones with *Spirifer Mosquensis*, and these are succeeded by a massive complex of strata comprising, both in the Ural and in the Donetz basins, coal-seams interbedded with massive Fusulina limestones. From the palæontological contents of this younger series in the Russian basins of deposition, V. von Möller concluded in the year 1875 that it was the equivalent of the Productive Coal-formation in Western Europe. Thus it was demonstrated that the Carboniferous system contained a definite palæontological sequence of extensive distribution.

In North America the Carboniferous formation has a wide surface outcrop, and as a rule consists of a Lower marine division (Sub-Carboniferous group) and an Upper productive division with coal-seams (Coal Measures). But in the Western States, especially in Illinois, Nebraska, and Missouri, beds of Fusulina limestone frequently replace the productive deposits or occur in alternation with them.

The Productive formation of the Carboniferous system has, on account of the great commercial value of the coal-seams, been examined in the very greatest detail not only in European lands but in all parts of the world. Survey maps of the coal-seams have been prepared on the largest scale, and afford evidence of the manifold diversity in the stratigraphical relations of the sandstone, conglomerates, shales, and coal-seams, and of the repeated tectonic disturbances to which in many districts these strata have been subjected since their original deposition as horizontal sheets of deposit.

In Germany the Saar basin has been mapped by Von Dechen and Nasse, the Westphalian Coal-formation by Lottner (1868), and the Carboniferous deposits in the Halle district have been surveyed and described by Laspeyres (1875).

Ferdinand Roemer in 1870 gave an accurate description of the coalfields in Upper Silesia, and in 1882 Schütze published an account of the Lower Silesian and Bohemian Coal deposits. The Saxony district was examined by H. B. Geinitz (1856), who tried to determine two palæontologically distinct zones in the Productive formation, a lower zone exhibiting chiefly Sigillarian remains, and an upper with Calamites and ferns in greater profusion. A similar sub-division was attempted by E. Weiss for the Coal Measures of the Saar basin, and Schütze and Stur also recognised sub-divisions of the Coal Measures in Hungarian districts But these sub-divisions can at the most have a local value; geologists agree that the fossil flora of the Coal Measures cannot admit of any general palæontological sub-division, as it presents a remarkably uniform character throughout all parts of the world.

E. *Permian System.*—The youngest system of the Palæozoic epoch has played a noteworthy part in the history of Stratigraphy. The industrial importance of the copper slate and the metalliferous "Zechstein" group in Germany secured it the attention of mineralogists for many centuries. The copper-bearing deposits and the Coal Measures formed the chief kernel of Werner's Flötz formations (*ante*, p. 58), and were selected by the earliest German stratigraphers, Lehmann and Füchsel, for extended field examination. The recognition by these stratigraphers of a definite series of lithological sub-divisions, together with their representation of the field-outcrop of these sub-divisions upon good maps may be regarded as the starting-point in Germany of the present methods in stratigraphical research. Füchsel and Lehmann tabulated the complete succession of the rocks now known as Permian, from the Red Underlyer or basal series of coarse conglomerates, shales, and sandstones, to the uppermost beds of limestone, dolomite, and marls in the "Zechstein" or mine-stone series. At that time the Zechstein series of Central Germany was not unnaturally confused with the stupendous masses of limestone, dolomite, and interbedded marls in the Alps and Jura mountains, and the apparent lithological resemblance of the series was the source of the mistaken conception held by early Alpine geologists regarding the age of the so-called "Alpine limestone" and "Jura limestone."

In England, Conybeare and Phillips identified quite

correctly the geological age of the Magnesian limestone and the Red Conglomerates of Devonshire with the Thuringian Zechstein group and the Red Underlyer series respectively.

Freiesleben, in 1807, gave an excellent systematic description of all the sedimentary rocks of Thuringia between the Red Underlyer and the Muschelkalk, comprising the whole succession under the name of *Kupferschiefer Gebirge* (Copper Slate Series). D'Omalius d'Halloy in 1808 termed the same complex *Terrain Penéen*, intending to give expression to the paucity of fossils in the rocks. Afterwards, in the second edition of his *Elemente der Geologie* (1834), D'Omalius d'Halloy confined the term "Terrain Penéen" to the Red Underlyer, Copper Slates, and Zechstein groups, and transferred the Bunter Sandstones with the Muschelkalk and Keuper series to the *Trias*, a designation for these three younger formations which had been introduced by Alberti.

In 1841, Murchison revealed the fact that a diverse lithological series of rocks, identical in age with the Red Underlyer and Zechstein, covered vast areas in the province of Perm and in the Eastern region of European Russia, and said Russia must be regarded as the typical district for these formations. He therefore proposed to give to the formations in question the name of *Permian System*, and classified the system as the youngest member of the Palæozoic succession. This name rapidly displaced D'Halloy's designation of Terrain Penéen, all the more as Geinitz and Gutbier, in their admirable monograph (1848-49) on the fossils of the German Zechstein and Red Underlyer, strongly recommended the name of "Permian System." On the other hand, Marcou objected to the name proposed by Murchison, on the plea that many of the geological sections of the Russian area were inaccurate, and that the rocks which Murchison had there ascribed to the Permian system were frequently of Lower Triassic age.

Jules Marcou recognised in 1853, for the first time, the Permian age of a series of dolomitic limestones, marls, shales, and conglomerates covering a large territory between the Mississippi and the Rio Colorado. The presence of the same complex was afterwards determined by Shumard (1858) in New Mexico; by Meek, Swallow, and Hawn in Kansas; by Worthen in Illinois, Missouri, and Nebraska; by Cope and White in Texas. Marcou observed two well-marked divisions in the American series just as in the European, and he

therefore suggested the name of *Dyassic* as a more suitable general term than Murchison's name derived from the Perm province. He further proposed to associate the Dyas and Trias as members of one great period in the geological succession, equal in rank with the next older Silurian and Devonian or greywacke period, and with the next younger Jurassic and Cretaceous period. H. B. Geinitz (1861-62) adopted Marcou's term of Dyas for the Permian system, and at the present day both names are usually given in the text-books.

The Dyassic deposits in the Saar and Rhenish district were investigated in detail by E. Weiss (1869-72), who proved the palæontological identity of the Fish, Amphibian, and Plant remains in the Lebach strata of the Saar basin with the Red Underlyer series in Lower Silesia and Bohemia, and transferred the Cuseler strata below the plant-bearing series from the Carboniferous system with which they had been erroneously included to the Dyassic system. Weiss also pointed out as important features of distinction that the lowest beds of the Red Underlyer or Lower Dyas occasionally contained workable coal-seams, and that the upper beds of the Lower Dyas were interbedded with thick flows of eruptive rocks (porphyry, porphyrite, melaphyre, etc.). Similar features were determined by the geologists of the Prussian Survey Department in the Harz, in Thuringia, and in Silesia, and by Credner and Sterzel in Saxony.

The structure and composition of the Copper Slate and Zechstein group, or Upper Dyas, had been so exhaustively treated by Lehmann, Füchsel, and Freiesleben that little remained to be added by recent research. From the predominance of fossil fishes and plant remains in the copper slates, and the frequent intercalation of thick deposits of salt between more calcareous fossiliferous portions of the Zechstein, the Upper Dyas of Central Europe is assumed to have taken origin in large inland seas, occasionally subject to periods of desiccation.

In the Central French plateau, the development of the Permian rocks is very similar to that in the Saar basin. The English deposits correspond more to the Thuringian development, and consist of the Red Underlyer group (locally called "Lower New Red Sandstones"), bituminous shales, Magnesian limestone, dolomite, marls, and gypsum. An

important monograph of the fossils in the Magnesian limestone was published in 1850 by W. King.

Whereas in the above-mentioned districts the Permian system appears to be composed of two well-defined members with distinctive lithological characteristics and faunas, Karpinsky made the observation in 1874, in the Ural mountains, that the Upper Carboniferous Fusulina limestones were conformably succeeded by a sandy and marly coal-bearing group of strata containing a rich marine fauna, transitional between the Carboniferous and Permian system. There were fossil types identical with Carboniferous species, others identical with Permian species, and still others that had not been previously found and were apparently peculiar to this group. Karpinsky therefore viewed this "Artinsk Étage" as a transitional group of strata between Carboniferous and Permian deposits. Russian geologists have proved its extension almost from the Arctic Ocean to the Caspian Sea, and frequently distinguish it as Permo-Carboniferous.

The marine fauna of the "Artinsk" group has also been identified in the Timan district of Petschora land, near Djulfa in Armenia, in Nebraska, and in the Salt Range of the Punjab district in India, where it occurs in the Lower and Middle Productus Limestone, and is succeeded by a young Permian fauna (Upper Productus Limestone). The fauna of the Indian Productus Limestones has been made the subject of an admirable work by Waagen, published in the *Palæontologica Indica* (1879-88).

In 1882, Fusulina Limestone of Permian Age with a richly diversified fauna was found in the Sofio Valley in Sicily. The fauna has been described by Gemmellaro, and appears to correspond in age with that of the "Artinsk" group. Frech referred the Fusulina limestones of the Carinthian Alps to Upper Carboniferous age; whereas Schellwien showed that the pale Fusulina limestones of Carniola contain a Permo-Carboniferous fauna.

In the Alps, the reddish Gröden Sandstones and Verrucano Conglomerates were demonstrated by Suess (1868), upon the evidence of fossil plant-remains, to be the equivalent of the Lower Dyas or Red Underlyer series. In the Venetian Alps and near Neumarkt, the Gröden Sandstones are succeeded by a series of interbedded dolomite, rauchwacke, and gypsiferous shales, which, according to Gümbel, are of the age of the

German "Copper Slate." The uppermost member in the Alpine succession is a bituminous marine limestone known as "Bellerophonkalk," from the large number of Bellerophon species contained in it. The fauna has a fairly diversified pelagic character, but G. Stache in his memoir on the Bellerophon Limestone (*Jahrb. k. k. geol. Reichs.*, 1887-88) showed that there were several species common to it and to the Zechstein of the German area.

A striking facies of the youngest Palæozoic and the oldest Mesozoic deposits occurs in Central and Southern India. Instead of the marine strata present in the Punjab, the deposits south of the Narbada river are of fresh-water origin, and comprise Conglomerates, Sandstones, and Carbonaceous shales. They were for the first time examined in detail near Talchir by the brothers Blanford (1856) and Theobald, and these geologists sub-divided the deposits into four palæontological groups (Nagpore, Talchir, Damuda, and Mahedewa groups). The lower divisions were placed in the Upper Permian formation, and the upper divisions were assigned to the lower Trias. The Talchir group consists of conglomerates with very large boulders and striated surfaces, and W. T. Blanford argued from this and other evidences that the boulders had been transported to their present position by means of icebergs, and that consequently there must have been an ice age during the latest Permian eras.

The whole complex of Permo-Triassic fresh-water strata, about 6000-7000 metres in thickness, received the name of *Gondwana System* from Medlicott, and according to the latest investigations, the lower members, including the Talchir and Damuda groups, are of Permian age, the "Panchet Series" is probably Triassic wholly or in part, and the upper horizons apparently represent a considerable portion of the Jurassic deposits. The lower members are especially subject to local variations, and the Talchir conglomerates repose unconformably upon different horizons of the older rocks.

The Kahabari, Damuda, and Panchet groups present intercalated coal-seams accompanied by fossil plants, amongst which the genera Glossopteris and Gangamopteris abound. The rich flora and the occurrence of remains of Vertebrates (Stegocephali and Anomodontia, cf. p. 417) give a distinctive impress to those groups, and render it difficult to find a comparison with European developments. Nevertheless, the com-

plete absence of true Carboniferous plant-types indicate that the Gondwana Coal-measures are younger than the Carboniferous epoch, and, on the other hand, the superincumbent strata of the Gondwana system contain Triassic plant-remains, hence the Glossopteris series in which the coal-seams occur are thought to be of Permian or possibly Permo-Triassic age.

A system resembling the Gondwana system of Southern India is present in South Australia, in South and East Africa, and in Brazil; littoral and fluviatile sandstones, conglomerates, shales, and locally well-developed Coal-measures form in all those localities the concluding group in the Palæozoic succession.

The similarity in the character of the deposits has suggested to geologists the idea that these areas may at that epoch have been connected with one another as the broken coast-line of some southern ancient continent, and this whole region of Permian coal-bearing deposits is sometimes referred to collectively for convenience as "Gondwana Land." Quite recently, a Glossopteris was found in the Russian Permian formation, and this discovery affords an important link in the comparison between the Russian facies and the facies of Gondwana Land. In South Africa, the Gondwana system consists of conglomerates, clays, and sandstones, and in these Permian species of Glossopteris have also been identified. This system rests unconformably upon Carboniferous rocks and is itself unconformably succeeded by shales, which pass upwards into the Karroo beds. The identification by Amalitzky of Permian Anthracosias at the base of the Karroo beds has led to the general assumption that the main body of the Karroo beds is of Triassic age.

The intimate connection of the Permian system with the Trias in the Southern Hemisphere, in India, and in Russia, appeared to confirm the views of Conybeare, who in 1832 had associated the Magnesian Limestone with the Red Conglomerates and the Bunter Sandstone as a united *Poikilitic* group. Brongniart applied the name *Poikilitic* only to the Bunter Sandstones; Buckland, in his ideal section of the earth's crust, combined the Permian and Triassic succession and termed it "Poikilitic System." Marcou (1859), John Phillips (1871), and the English Committee of the International Congress of Geologists in London (1888), supported the union of the Dyas and Trias into one group, to be placed in the

Mesozoic epoch. But in North America and on the Continent there has been an adverse current. The near relationship of the floras and faunas of the Permian deposits with those of the Carboniferous seemed to make it injudicious to draw any such sharp line of division at the conclusion of the Carboniferous period as would be indicated if the Permian rocks were transferred to Mesozoic time. And so close had the relationship between the Permian and Carboniferous systems appeared, that A. de Lapparent, in the first two editions of his admirable Text-book of Geology, had united them under the name of "Permo-Carboniferous System."

F. *The Triassic System.*—The fossils preserved in the older horizons of the Triassic system in Western and Southern Europe afford evidence that the plants and animals which flourished and abounded in these areas during Permian and earlier epochs had largely given place to new forms of life. European geologists therefore sought to give expression to local disconuities of the palæontological chain by regarding the Triassic system as the first of a Mesozoic epoch, when the characteristic forms of life were intermediate between the faunas and floras of the very ancient or Palæozoic epochs and the younger or Cainozoic epochs. The Mesozoic epoch is subdivided into three systems or formations: Triassic, Jurassic, and Cretaceous.

In the eighteenth century, Lehmann and Füchsel recognised in Thuringia the Bunter (or variegated) Sandstone and Muschelkalk (or shell limestone) as independent members of the Flötz series, and had separated them from the Red Underlyer and Zechstein. The characteristic fossils of the Thuringian Muschelkalk are admirably described and figured in Schlotheim's *Nachträge zur Petrefaktenkunde* (1823). Nevertheless, there was for a long time great insecurity in Germany regarding the Bunter Sandstone and the limestone above it, as many geologists, even such travelled observers as Leonhard, Charpentier, and Voltz, confused the Bunter Sandstone with the North German Underlyer, and the grey limestone or Muschelkalk with the Zechstein.

Peter Merian, in his first treatise (1821) on the geology of the neighbourhood of Bâle, was uncertain about the stratigraphical position of the Bunter Sandstone, but showed that this horizon of rock was succeeded both in the Vosges and in

the Black Forest by grey limestone with uneven surfaces and extremely rich in Telebratulas and Lamellibranchs, and that the fossiliferous limestone was succeeded by variegated marls with interbedded layers of sandstone and gypsum. But although Merian quite accurately described the strata which were afterwards recognised to be Muschelkalk and Keuper, the special palæontological literature was scarcely sufficiently advanced to permit of his identification of the age of the rocks, and he regarded them both as equivalents of the Jura limestone.

In North Germany, Hausmann (1824) and Hoffmann (1823 and 1830) elucidated with praiseworthy accuracy the stratigraphical relations of the Bunter Sandstone, Muschelkalk, and the superposed marls and clays with each other and with the lower formation of the Zechstein and the Red Underlyer.

About the same time, in 1825, the relations of the series were explained in the Upper Rhine district by three geologists who made a journey together—Oeynhausen, Dechen, and La Roche. It was in their work that the term "Keuper" was first applied to the bright-coloured marls and clays above the Muschelkalk. The term originated as a corruption in common use in Coburg, and had been suggested by Leopold von Buch in a letter to Merian.

The rocks of Wurtemberg were described in 1826 by Alberti,[1] primarily with a view to the investigation of their minerals, but the work proved to have a high geological value. It provided an accurate account of the Bunter Muschelkalk and Keuper in that area. In 1831 Merian published his description of the same formations in the southern part of the Black Forest. Still more detailed was the excellent description of the Vosges mountains and the adjacent portions of France with which Élie de Beaumont commenced his geological career.

The eminent Frenchman divided the Sandstone series in the Vosges into three distinct groups:—1, The Lower Red

[1] Friedrich August von Alberti, born in 1795 in Stuttgart, studied mining and finance in his native town, began his official career in 1815 at the saltworks at Sulz, and in 1820 was appointed Inspector of Saltworks at Friedrichshall. He bored rock-salt at Schwenningen, and was made a Councillor of Mines in 1836, and from 1852 to 1870 manager of the Friedrichshall Saltworks, where he successfully entered a new shaft. He died in *1878* at Heilbron.

Sandstone, with conglomerates and red clay; 2, the Vogesen Sandstone; 3, the Bunter Sandstone (*grès bigarré*). The Vogesen Sandstone was regarded by Élie de Beaumont as an equivalent of the Zechstein or Red Underlyer series, and he thought the uprise of the Vogesen had taken place after its deposition. The Bunter Sandstone was described as sometimes succeeding it unconformably, sometimes dissociated from it by faults. On the other hand, the Bunter Sandstone was said to pass gradually upward into Muschelkalk and the latter into Keuper deposits (*marnes irrisées*).

In the year 1834 Alberti published his classic *Monograph of the Bunter Sandstone, Muschelkalk, and Keuper, and their union as a formation.* Alberti suggested that the name of *Trias* be given to this formation, on the basis of the well-marked character of the three sub-divisions. Starting from his own observations in South-Western Germany, Alberti drew a comparison between the deposits of the same age in other parts of Europe. Each of these three main divisions of the Trias was again sub-divided into a series of groups or horizons of rock, which are all carefully established upon stratigraphical, lithological, and palæontological data.

Alberti's sub-division of the Trias has remained the standard of research in Germany, although one or two slight modifications have been made. In other countries the name was also accepted, and the development of the Trias in Germany was regarded as the leading type in Europe of the sedimentary succession which had accumulated during that period in the large inland seas and lakes intermittently in open communication with the sea. The Muschelkalk, which represented the longest period of marine conditions in the German area, was found however to be entirely absent in certain areas.

William Smith had early pointed out the absence of the Muschelkalk in Great Britain. Later researches by Conybeare and Phillips, by Strickland (1833-37), by Murchison and Buckland (1839), showed that in Great Britain the Bunter beds are largely of estuarine origin, composed of sandstones, pebble-beds, and conglomerates, while the Keuper beds are also in places conglomeratic, or are red and white sandstones, and pass upward into the characteristic red and green marls containing local beds of gypsum and thick layers of rock-salt.

A summary of the Triassic Succession was given by Quenstedt in his *Flötz Series of Wurtemberg* (1843). Quenstedt

differed from Alberti on certain points respecting the sub-division, and the differences of opinion have been continued by the adherents of the one view or the other until the present day. The differences arose solely as to the best mode of treatment of the passage-beds from Bunter to Muschelkalk, and from Muschelkalk to Keuper. The "Wellendolomit" or wavy-surfaced dolomite, which occurs at the passage from the Bunter sandstones to the typical limestones of the Muschelkalk group, were placed by Alberti at the base of the Muschelkalk, whereas Quenstedt preferred to give them an independent position, or to include them with the Bunter sandstone. Again, the "Lettenkohle," or passage group between Muschelkalk and Keuper, which comprises a series of marls and clays with thin coal-seams, was placed by Alberti at the base of the Keuper, and Quenstedt placed it as the uppermost horizon of the Muschekalk. In later publications both authors adhered to their opinions; Alberti made one slight change in transferring the dolomitic limestone ("Trigonodus limestone" of Sandberger) from its association with the Muschelkalk to the base of his "Lettenkohle" group, thus adding to the security of the systematic position to which he had assigned the Lettenkohle group.

As Alberti's sub-divisions have been fundamental in the literature, and will be convenient for reference in the subjoined pages, the list may be shortly stated :—

	Sub-division of German Trias.	Palæontological Character.
Upper Keuper Group, or "Gypsum Keuper."	Tübingen sandstone (with bone-beds).	(Afterwards distinguished as Rhætic or Infra-Lias): ***Avicula contorta***, ***Estheria minuta***, ***Cardium Rhaticum***, ***Belodon***, ***Microlestes antiquus***, etc.
	"Keuper" marls and arkose sandstone, dolomitic marls, "waterstones" (compact sandstones), gypsum and variegated marls.	Occasional occurrences of plant, fish, and labyrinthodont remains.
Lower Keuper or "Lettenkohlen" Group.	Upper limiting band of grey dolomite and limestone, dark clays, earthy coal and sandstone, dark clays and shales, earthy coal and gypsum.	*Myophoria Goldfussi*, ***M.*** *transversa*, *Lingula tenuissima*, etc., *Voltzia heterophylla*, *Estheria minuta*, *Bairdia;* Fish and Saurian remains.

	Sub-division of German Trias.	Palæontological Character.
Friedrichshall Limestone (Up. Muschelkalk).	Dolomitic limestone - -	*Trigonodus Sandbergeri*, etc.
	Friedrichshall limestone -	*Lima striata*, *Terebratula vulgaris*, *Nautilus bidorsatus*, *Ceratites nodosus*, etc., richly fossiliferous.
	Oolitic rock (Rogenstein) -	
	Encrinite limestone - -	*Encrinus liliiformis*, etc.
Anhydrite Group (Mid. Muschelkalk).	Dolomite, marls, porous limestones, bituminous limestone, gypsum, anhydrite, clay and rock-salt.	Saurian remains occasionally occur, otherwise poor in fossils.
Wellenkalk Group (Lr. Muschelkalk).	Wellenkalk (wavy limestone) Wellendolomit (wavy dolomite).	Richly fossiliferous, *Terebratula vulgaris*, *T. angusta*, *Spiriferina fragilis*, *Gervillia costata*, *Myophoria elegans*, etc. *Encrinus liliiformis*.
Bunter Sandstone Group.	Variegated clays and marls, chiefly *red* clays with gypsum and salt.	*Myophoria costata*, *M. vulgaris*, plant remains, *Equisetum*, *Voltzia*, etc.
	Bunter sandstone - - -	Labyrinthodont remains and amphibian footprints.
	"Vogesen sandstone" (false-bedded fine sandstone interbedded with dolomite and oolite).	*Estheria minuta*, etc.

The later literature on German Trias is very voluminous. Gümbel, Sandberger, and Thürach have materially advanced the stratigraphical and palæontological knowledge of this subject by their exhaustive studies of Bavarian areas. Daubrée, Benecke, and Lepsius have been amongst the geologists who have investigated the Trias in Alsace-Lorraine. In the Rhine provinces, Weiss and Blanckenhorn have been the chief workers. The isolated Triassic outcrop at Rüdersdorf, near Berlin, has been made the subject of a monograph by Eck, and the Upper Silesian area of Trias has been described by Eck and Ferdinand Roemer.

Only after a clear exposition had been obtained of the general stratigraphical relations of the Trias in extra-Alpine European localities, could the difficult task be seriously commenced of unravelling the tangled skein of the Triassic rocks in the Alps. To determine the relations of Triassic rocks in

the field, to define their true succession, to distinguish their diverse local developments, to comprehend their remarkable metamorphosis due to chemical and dynamical causes, have been some of the chief themes in Alpine geology for the last fifty years. The most skilled Alpine geologists have devoted their energies to the difficulties of the Alpine Trias, and still it is only possible to record a partial success.

To go back to Leopold von Buch, that experienced geologist several times travelled in South Tyrol, the Salzkammergut, Styria, and Carinthia, and published a series of pamphlets which, though short, were closely packed with observations on the stratigraphy. A small map of South Tyrol appeared in 1822 giving a general survey of his results, and it shows how very little information he had gleaned regarding the geological age and relations of the masses of "Alpine Limestone," and the members of the Secondary Alpine rocks generally.

Keferstein compiled a geognostic map of Tyrol and Vorarlberg in 1821; it shows at the north edge of the Alps a small band of Bunter Sandstone striking from Brixlegg to Kitzbichel, reappearing in the Kloster valley of Vorarlberg, and continuing westward from that to Lake Walen. In the southern Alps the Schlern mountain, near Botzen, is surrounded by a horseshoe-shaped outcrop of sandstone, and at the Peitler Kofl a sandstone and conglomerate band begins which follows the Puster valley eastward and ceases at Innichen. The broad tracts of limestone north and south of the Central Alps are simply indicated with one colour on Keferstein's map and designated "Alpine Limestone" (Zechstein).

The coloured geological map of Germany compiled by Buch, and published by Schropp in Berlin (1826), showed no noteworthy advance in the Alps, neither was there much additional insight to be gained from Sedgwick and Murchison's Geological Sketch-map of the eastern Alps (1831). In the latter the extension of the red sandstone is fairly correctly entered in North Tyrol, in the Salzkammergut, in Styria, Carinthia, and Carniola; the zones of limestone on the north and south are still left undivided, although they are treated as "Jura" limestone instead of Zechstein. This map and several geological sections accompanied a treatise on the *Structure of the Eastern Alps*, by the two famous British geologists. Their contribution to Alpine literature was scarcely less powerful in its influence than their works on the Palæozoic rocks of Great Britain. By

its numerous sections and correct fundamental conceptions of the tectonic relations of the various groups of strata, their *Sketch of the Structure of the Eastern Alps* provided the first intelligible wayboard for the student of the geology of the Tyrol, and was recognised as the starting-point of further research.

Excellent special sections were worked out by Lill von Lilienbach in the Salza Valley from Bischofshofen and Werfen to Teisendorf (1830), and from Werfenweng through the Tännen Range to Mattsee (1833). These afforded a true representation of the stratigraphical succession of the rock-groups which compose the northern limestone Alps, but Lill went far astray in the vague attempts which he made to identify the Alpine rocks with extra-Alpine formations. One of his most noteworthy contributions was his careful determination of the guiding thread supplied by the reddish and greenish "Werfen" shales, whose name is taken from their typical development at Werfen in that area. Lill traced them everywhere as the basis of the Alpine limestone, but he erroneously assigned them and a considerable part of the limestone to the Wernerian "transitional" series (*ante*, p. 58). Lill's chief stratigraphical results may be summarised in tabular form :—

Upper Alpine Limestone, comprising the "Hippurite" limestone of Untersberg, etc.

Middle Alpine Limestone (regarded as Jurassic).	Shales and sandstones with clays, gypsum, and the salt deposits of Hallein, Berchtesgaden, Hallstadt, and Aussee; Rossfeld and Schellenberg strata.
Lower Alpine Limestone, doubtfully indicated as "transitional formations."	Red marble of the Dürnberg; Adneth limestone with Ammonites; limestone and dolomite of the Watzmann, Tännen, and the Hohe Göll groups.

Werfen Shales with interbedded gypsum (regarded by Lill as a "transitional" formation).

H. G. Bronn examined the fossils collected by Lill, and in a supplementary paper to Lill's in the *Neues Jahrbuch* (1831), emphasised the unusual character of the fauna of Ammonites and Monotis present in the Dürnberg limestone, and its apparent affinities with Liassic and Transitional marine faunas.

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Bronn regarded the middle Alpine limestone as Jurassic or Liassic. In comparison with these indefinite surmises regarding the age of Alpine limestone deposits, the secure identification of Muschelkalk in the neighbourhood of Recoaro and Rovegliano by Maraschini (1822), Catullo (1827), and Murchison makes a refreshing impression.

The discovery of the wonderfully rich fossil locality of St. Cassian in South Tyrol proved a turning-point in the history of Alpine geology. Leopold von Buch had brought St. Cassian fossils with him from one of his journeys in the Dolomites, and he sent them to Count Münster for identification. In 1834 Count Münster published in the *Neues Jahrbuch* the description of a large collection of St. Cassian fossils, most of which had been sent to him by Lommel. Of one hundred and twenty-eight species, Münster thought he could identify seven as Muschelkalk species, two as Liassic, and six as Jurassic. Münster's famous work published in 1841, entitled *Beiträge zur Petrefaktenkunde*, is a monograph of the St. Cassian fauna. The investigation of four hundred and twenty-two species of Mollusca, Brachiopods, Echinoderms, Corals and Sponges by Count Münster led him to conclude that twelve of the St. Cassian species also occurred in the Carboniferous limestone and Zechstein, ten in the Muschelkalk, eleven in the Liassic, and three in the Jurassic rocks; of these so-called "common species" thirteen are said to be actually identical, the others analogous. Count Münster could not ascertain any definite palæontological sequence that would harmonise with the stratigraphical succession then commonly accepted for the Tyrol.

Münster's palæontological work contained an introductory geological part written by H. L. Wissmann. The succession of the strata between St. Lorenzen and St. Cassian and at the northern side of the Schlern Mountain was described by Wissmann. He called the red sandstone and the shaly and calcareous strata immediately above the Botzen Porphyry *Seis strata*, from the name of a village Seis at the base of Schlern Mountain, and explained them as identical with the "Werfen Strata" which had been described in North Tyrol. Leopold von Buch had previously identified the red sandstones of this group with the "Bunter Sandstones" of Germany, and the shaly and calcareous strata with the "Wellenkalk" or lower horizon of Muschelkalk in Germany. The "Seis Strata" are as a rule suc-

ceeded by thick masses of dolomite. These were at that time termed "Fassa Dolomite" from the Fassa or Avisio Valley, the leading valley of the district.

Buch had explained the dolomitic character of the "Fassa Mountains" as the result of alteration associated with the local volcanic action, but Wissmann regarded the "Fassa Dolomite" as a normal marine deposit. With regard to the marly St. Cassian strata characterised by the richly diversified small-sized fauna, Wissmann could not find out what were the relations of this group either to the Fassa Dolomite or to the marls and shales of two other fossiliferous localities near St. Cassian, namely, the village of Wengen, and the hill-slopes on which the pilgrimage chapel of "Heilig-Kreuz" had been built.

In 1843, Klipstein published a geological and palæontological account of the same districts. His observations in Abtey and Fassa valleys had been taken in unusual detail, but led to no satisfactory explanation of the tectonic relations of the district. Klipstein, who made personal collections to a certain extent and also bought largely from the village fossil-collectors, was enabled to add more than three hundred new species to the known fauna of St. Cassian. The investigation of these was unfortunately in no measure comparable with Münster's work, and the fallacious identification of a Cephalopod as *Ammonites cordatus* led Klipstein to place the Wengen shales in the Liassic formation, and as the Wengen shales pass upward into St. Cassian marls, he concluded the latter were of Jurassic age. Bronn, in a review of Klipstein's work, in 1845, expressed grave doubts about the Liassic and Jurassic age of the Wengen-Cassian series, and stated that in his opinion these shales and marls were possibly members of the Triassic formation which had remained hitherto quite unknown, and for which no comparison could be found in the German Trias, or they represented an aberrant "facies" of the Muschelkalk.

In 1844, Emmrich contributed a short communication to the *Neues Jahrbuch* on "The Stratigraphical Succession of the Flötz Series in the Gader Valley, at the Seis Alp, and St. Cassian." This work created a new era in the study of these deposits and takes its rank as one of the classic contributions to Alpine geology. In the course of a short visit to South Tyrol, Emmrich prepared geological sections from the

Pufls Ravine to the Seis Alp, and in the Gader Valley; by this means he ascertained that the "Seis Strata" begin with alternating dark-red and white sandstone, pass upward into red calcareous, micaceous, and thin-bedded shales with Myacites Fassaensis, and these are succeeded by a complex of grey calcareous beds resembling "Wellenkalk," containing *Posidonomya Clarai.*

The succession of strata, as Emmrich recognised it, may be shortly tabulated—

7. *Dolomite.*
6. *Fossiliferous St. Cassian Strata,* which build up the Seis Alp, and nearer Schlern at the Cipit Stream yield numerous fossils.
5. *Wengen Strata with Halobia Lommeli.*
4. *Unfossiliferous Complex.*
    (*f.*) Calcareous rock resembling Wellenkalk.
    (*e.*) Dark limestone and siliceous concretions.
    (*d.*) Light grey shaly limestone.
    (*c.*) Dark bituminous limestone.
    (*b.*) Dolomite.
    (*a.*) Limestone with irregular bedding surfaces.
3. *Limestone with Posidonomya Clarai.*
2. *Shales with Myacites Fassaensis.*
1. *Seis Sandstone.*

Emmrich's succession was taken as the model by all subsequent stratigraphers, and became rapidly recognised as the normal section of the South Tyrol Trias. Thus the interest aroused by the St. Cassian fossils had culminated in providing the first clue to the particular character of the difficulties which had to be faced in Alpine geology. The Alpine equivalents of the Bunter or lower Trias had been clearly elucidated, the Muschelkalk had been identified; and the Wengen-Cassian group above it had demonstrated the actual presence of a fauna and a lithological succession different from that presented in the Muschelkalk or succeeding horizons in any known extra-Alpine area. The principle of local developments of rock of contemporaneous origin, but containing distinctive faunal assemblages, was now appreciated, and geologists had also more hope of being able to fix the relative age of masses of "Alpine Limestone" according to their stratigraphical position *below* or above the fossiliferous Wengen-Cassian group

In the year 1846, Hauer's first monograph of the Cephalopods in the Hallstatt limestone appeared, and also a treatise by the same eminent author on the Molluscan marble of Bleiberg in Carinthia. Hauer demonstrated the identity of some of the species in these calcareous rocks with St. Cassian species, and thereby founded the knowledge of the younger horizons of Trias in the northern Alps. Further contributions by Hauer in 1847 and 1849 corroborated the great abundance of the Cephalopod fauna in the limestone rock in the neighbourhood of Hallstatt and Aussee, and showed that it was no less varied in its character than that of St. Cassian. The characteristic gastropods from the Hallstatt limestone were described by Hoernes.

Although Hauer's comparison of the fauna of the Hallstatt marble with that of the St. Cassian marls had given an indication of the age of this particular Alpine limestone, and had shown it to be unquestionably distinct from the Liassic limestone of Adneth, Morlot (1847) still regarded the Alpine limestone, in accordance with the earlier work of Murchison and Buckland, as Liassic or Jurassic. In a work otherwise very admirable in many ways, *The Explanatory Text of a Geological Sketch-Map of North-Eastern Tyrol*, Morlot entirely ignored all sub-divisions of the "Alpine Limestone" that had been previously attempted. The Geognostic Map of Tyrol, published in 1849 by the Mountaineering Club of Tyrol and Vararlberg, merely differentiated lower, middle, and upper Alpine limestone, without assigning a definite age to any of the groups.

A general review of the literature and the position of geological research was written by Hauer in the year 1850, after the Imperial Geological Survey Department had been established in Austria. According to Hauer, the Alpine equivalents of the Bunter sandstones are the Werfen strata, the Sernft shales and conglomerates of the northern Alps, the Seis strata in South Tyrol, and the red sandstones and conglomerates in Carinthia and Carniola. A considerable part of the Alpine limestone belongs to the Trias; to the Lower Muschelkalk may be referred the so-called Isocardia limestone with "Dachstein bivalves" in the Salzkammergut, in Bavaria and Vorarlberg, and the Dolomite with *Cardium triquetrum* in the southern Alps. To the Upper Muschelkalk (or Keuper?) belong the marbled limestones of the Salzkammergut with Ammonites and Monotis, the Wengen, St.

Cassian, and Bleiberg strata, and a part of the carbonaceous deposits in the Vienna sandstone (Lunz strata). Hauer at that time regarded the Hallstatt limestone as younger than the Dachstein limestone.

The organised efforts of the Austrian Geological Survey rapidly extended the knowledge of Alpine geology. In 1853, the Survey Reports sub-divided the Triassic formation of North Tyrol into two groups: 1, *the Werfen strata and Guttenstein limestones* (equivalents of the Bunter sandstone and Lower Muschelkalk respectively); and 2, *the Hallstatt strata* (or Upper Muschelkalk). The salt deposits were said not to be intercalations in Alpine limestone, as Lill von Lilienbach had assumed, but, according to Stur and Suess, belonged to the Werfen strata. The Hallstatt strata were now said to repose on the Guttenstein strata and to be *succeeded by Dachstein limestone*, and on the evidence of Lipold the *Dachstein limestone* was united with the *Kössen* (Gervillia) strata and referred to Liassic age.

There still seemed no means of determining the stratigraphical position of the dolomitic rock in the north Alps. Hauer, in his report, mainly relied upon two valuable works, the first a memoir by Emmrich (1853) on the eastern part of the Bavarian Alps, and the other by Escher von der Linth (1853) on the geology of Vorarlberg.

With considerable insight, Emmrich had distinguished in the Bavarian Alps a series of well-marked life zones in the Mesozoic rocks:—

Cenomanian -	9.	Orbitulina sandstone (cf. p. 244).
Neocomian -	8.	Aptychus shales (cf. p. 405).
Jurassic - -	7.	Haselberg marble passing into the Tithonian group.
Liassic - -	6.	Amaltheus marls with *Amm. Amaltheus*, etc.
Saliferous System and St. Cassian Series.	5.	Gervillia beds or Kössen strata with *Avicula contorta*, etc.
		Oolitic limestones with *Koninckina Leonhardi* and other St. Cassian types.
	4.	Lithodendron limestone (cf. p. 250).
Muschelkalk -	3.	Middle Alpine limestone with *Halobia Sturi*, etc.

Wellenkalk -	2. Lower Alpine limestone, dolomite, and rauchwacke, with *Terebratula vulgaris*, *Myophoria vulgaris*, etc.
Bunter - -	1. Red sandstone, Werfen shales with *Monotis Clarai*, etc.

Emmrich enumerated a larger number of fossils in the Avicula contorta zone which had hitherto been referred to the Liassic group, and in opposition to the views of Buch, Murchison, Lill von Lilienbach, and Schafhäutl, he pointed out the strong affinities exhibited both by the Avicula beds and the Lithodendron limestone with the St. Cassian series.

In the Vorarlberg, Escher von der Linth, partially in collaboration with Merian, made the following sub-divisions of the Wengen-Cassian group in the Triassic series:—

St. Cassian Group.	Megalodon dolomite ("Dachsteinkalk" or "Main dolomite").
	Upper St. Cassian strata with *Gervillia inflata*, *Cardium Rhæticum*, etc.
	Dolomite or middle St. Cassian ("Esino Kalk").
	Black marls with *Bactryllium Schmidti* and limestone with *Halobia Lommeli* (lower St. Cassian) plant sandstones with *Equisetum*, *Calamites*, etc.

In this sub-division the upper St. Cassian strata of Escher correspond to the "Gervillia" strata of Emmrich; and this confusion of the St. Cassian marls with the Kössen marls proved a frequent source of error in after years, and also led to a consequent misinterpretation of the age of the limestone or dolomite masses underlying the fossiliferous marls or reposing upon them. Escher's Halobia Lommeli sub-division is identical with the "Wengen" strata of Emmrich's South Tyrol section.

Important researches were made in the Trias of Lombardy by Curioni (1855). He confirmed Escher's sub-divisions, showed that the Halobia Lommeli strata and plant sandstones rested upon Muschelkalk, and gave careful details regarding the fossils and superposition of the lower and middle Triassic

horizons. Certain fossiliferous marls with *Myophoria Whateleyi* and *Kefersteini* were described by Curioni, and identified with St. Cassian strata. The Esino limestone of the Lombardy Alps, which had been placed in Escher's succession *below* the "Megalodon" (Dachstein) dolomite, was ascribed by Curioni to a position *above* this dolomite.

The geological section of the Alps from Passau to Duino, which was prepared by Hauer, represents the high-water mark of the geology of the eastern Alps in the year 1857. The interposition of the "Raibl" strata, characterised by *Myophoria Whateleyæ* at the base of the Dachstein limestone, was the chief advance upon the previous systematic attempts. The position, extension, and fauna of the Raibl strata had been described by Ami Boué as far back as 1835, and twenty years later in more detail by Fötterle. In 1857, Hauer published a special monograph of the Raibl fauna, which was supplemented in 1858 by Bronn's description of the fishes, crustacea, and plants of the black Raibl shales. These works undoubtedly helped to elucidate the faunas of the southern zone of the Alps.

Three highly fossiliferous series of earthy deposits had now been determined in the midst of the masses of Alpine limestone:—*Kössen* beds, in which Leopold von Buch had first found Gervillias and other bivalves near Tegern See in Bavaria (1828); the *Raibl* series and the *Wengen-Cassian* series; moreover, the pelagic faunas of the calcareo-dolomitic rocks had been fairly well investigated. It might, therefore, have been reasonably expected that the stratigraphical difficulties would no longer prove so insurmountable. As a matter of fact, these seemed in no way diminished, and this was in itself an indication that the palæontological method, which had been so successfully applied in the case of the English Jurassic formation in the Paris basin, or the German Trias, was not enough to unlock the mysteries of Alpine structure. The Triassic succession given by Hauer for the southern Alps in 1858 may be quoted, since it held the place of authority with the Austrian Survey for several decades. He differentiated in the geological map of the Lombardy and Venetian Alps the following seven horizons as a palæontological sequence:—

Infralias.	7.	Kössen strata.
	6.	Dachstein limestone and dolomite.
Upper Trias.	5.	Raibl strata of Gorno and Dossena.
	4.	Esino limestone.
	3.	St. Cassian strata.
Middle Trias.	2.	Wengen strata and Rauchwacke. Muschelkalk.
Lower Trias.	1.	Servino and Werfen shales. Verrucano conglomerate.

Stoppani, the Italian geologist, in a similar work published in 1857, discussed the Lombardy Alps. He regarded the Verrucano conglomerate as a Palæozoic horizon, and otherwise his sub-divisions were comparable with Escher's. The dark bituminous shales of Perledo, near the Lake of Como, with Fish and Saurian remains, were correctly assigned by Stoppani to the Muschelkalk; while the dolomitic limestones with *Encrinus*, *Terebratula angusta*, *Spirifer fragilis*, etc., at Monte Salvatore near Lugano, Menaggio, and other localities, were recognised as *lower* horizons of Muschelkalk. Stoppani also published a valuable monograph of the fauna of the Esino limestone (1858-60), and upon palæontological grounds identified the age of the Esino limestone with that of the Hallstatt and St. Cassian groups. Unfortunately, however, Stoppani in a later publication withdrew this comparison, united the Esino limestone with the dolomite containing *Avicula exilis* (Dachstein dolomite), and placed the whole complex above the Raibl strata in the horizon of the main dolomite of the northern Alps.

In the year 1854, Suess published a monograph of the Brachiopods of the Kössen strata. Under the name of Kössen strata, Suess understood the "Gervillia strata" of Emmrich and Schafhäutl, as well as the "Upper Cassian strata" of Escher. He gave a general exposition of the stratigraphical relations of the Kössen strata to the Dachstein and Lithodendron limestones and the bituminous fish shales of Seefeld. Suess argued that as the whole complex reposes on the Hallstatt strata, and is succeeded by strata containing Upper Lias fossils, it ought to be included with the Gresten strata as Lower Lias. Merian immediately objected to this view. He

contested with justice that the Kössen strata were marine equivalents of the Upper Keuper, and a quite distinct formation from the Gresten strata and the limestone with Liassic Ammonites at Enzesfeld and Hörnstein. In the same paper, Merian reported some additional Austrian localities where true St. Cassian fossils occurred—at Telfs, in the Lavatsch Valley, and at Haller Salzberg.

In the autumn of 1854, Gümbel commenced his investigations in the south-west Bavarian Alps and the adjacent parts of Vorarlberg and North Tyrol, and his first memoirs appeared in the Jahrbuch in 1856. They afforded valuable information on the tectonic relations and palæontological sub-division of the Cretaceous deposits in those Alpine areas. Gümbel showed that four quite different horizons of Triassic, Liassic, and Tertiary shales had been thrown together under the name "Flysch," applied by Schafhäutl and other authors.

In the summer of 1857, the memorable geological tour of the North Tyrol and Vorarlberg Alps took place, in which Hauer, Richthofen, Fötterle, Gümbel, Pichler participated, and were for a few days joined by Escher von der Linth and Cotta. The geological survey of Vorarlberg was then assigned to Richthofen, who had also to draw up the combined report. Gümbel was to provide the supplementary data from the Bavarian Alps.

Richthofen demonstrated in the first instance that the thickness of the Triassic deposits diminishes very perceptibly when followed from east to west, and is very much reduced in the Vorarlberg. He then presented in tabular form the parallelism of the Triassic sub-divisions at different parts of the Alps:—

	Vorarlberg.	Eastern Tyrol.	Salzburg.
Lias.	9. Upper Dachstein limestone.	Upper Dachstein limestone.	Upper Dachstein limestone.
	8. Kössen strata.	Kössen strata.	Kössen strata.
	7. Lower Dachstein limestone.	Lower Dachstein dolomite and limestone.	Lower Dachstein dolomite and limestone.

Upper Trias.	6. Raibl strata with gypsum and rauch-wacke.	Raibl strata.	?
	5. Arlberg lime-stone.	Hallstatt lime-stone (resp. Wetterstein)	Hallstatt limestone.
	4. Partnach strata.	Partnach strata.	?
	3. Virgloria lime-stone.	Virgloria lime-stone.	Virgloria limestone.
Lower Trias.	2. —	Guttenstein limestone.	Guttenstein limestone.
	1. ?	Werfen strata.	Werfen strata.
	Verrucano Con-glomerate (prob-ably Palæozoic).		

It will be seen that Richthofen sub-divided the true Trias, exclusive of the Dachstein limestone and Kössen beds, into two groups, upper and lower, which are applicable both in the northern and southern Alps. The Werfen strata pass upward into the black, poorly-fossiliferous limestones for which Hauer had introduced the name of *Guttenstein strata.* In 1852, it had been shown by Kudernatsch that the upper layers of these strata contain numerous hornstone concretions, are thinly-bedded, and nodular.

Several Brachiopod species (*Terebratula trigonella*, *Spirifer fragilis*, *Mentzeli*, etc.) were found in these upper horizons by Pichler in the neighbourhood of Innsbruck, and by Escher near Reutte. Richthofen found Ammonites and Bivalves resembling *Monotis* in these layers at the Virgloria Pass, and the characteristic Brachiopods in the Lichtenstein area. As the Guttenstein limestones frequently alternate with Werfen strata in the eastern Alps, Richthofen separated the Guttenstein strata from the upper more characteristic hornstone layers, and called the latter *Virgloria Limestone.*

Gümbel had found in the Partnach ravine, near Partenkirchen, marly shales with *Halobia Lommeli* (afterwards called *H. Parthanensis*) and *Bactryllium Schmidti.* Above these marls and shales in the Vorarlberg, Richthofen had found a dark-

coloured limestone which he had termed "Arlberg Limestone"; in Bavaria and North Tyrol the Partnach shales are succeeded by a light, pure limestone (afterwards called "Wetterstein Limestone") with *Chemnitzia* and *Diplopora annulata.* These limestones were identified by Richthofen with the Hallstatt limestone in the Salzkammergut.

Richthofen's demonstration of the occurrence of the Raibl strata in North Tyrol is especially important. Oolitic limestones and plant-bearing sandstones associated with rauchwackes and gypsum had been observed by Escher in Vorarlberg, and called Lower St. Cassian strata. The same series observed by Pichler and Gümbel in North Tyrol and Bavaria were called "Cardita Strata," from the frequency of the fossil *Cardita crenata.* Like Escher, Pichler and Gümbel also referred them to the age of the typical St. Cassian strata in South Tyrol. The occurrence of a fair number of fossils identical with those in the south Alpine Raibl strata led Richthofen to identify this group of fossiliferous strata in the northern Alps as "Raibl Strata," although he admitted that the Raibl strata in North Tyrol seemed to have a greater number of fossils in common with the St. Cassian series than was the case in the typical "Raibl Strata" at Raibl in Carinthia. He supposed, therefore, that the Raibl strata in North Tyrol were slightly older than those in the southern Alps.

The unfossiliferous calcareo-dolomitic masses of rock above the Raibl strata in Vorarlberg were compared by Richthofen with the Dachstein limestone in the Salzkammergut; in Vorarlberg, the dolomitic masses passed upward into Kössen marls and limestones with Megalodon triqueter. The tectonic relations in Vorarlberg were elucidated by Richthofen by means of a number of excellent geological sections.

Another work by Richthofen, which was destined to have an even wider influence upon Alpine geology than his admirable exposition of the Triassic succession in North Tyrol and Vorarlberg, was his *Geognostische Beschreibung der Umgegend von Predazzo, St. Cassian, und der Seisser Alp.* This classical work appeared as an independent publication in the year 1860, but the author's geological observations had been taken in the summer of 1856. The work was greeted on its appearance with the highest recognition from all sides, and the author, who was little over twenty at the time, was looked upon as one of the first Alpine geologists.

After a historical introduction and exhaustive enumeration of the previous scientific literature in any way connected with the area, Richthofen describes the general surface conformation of the area, and gives the reader a clear conception of the topographical idiosyncrasies of the areas under examination. Then follows a description of the formations and rocks, which omits nothing of lithological, mineralogical, or palæontological interest or significance. Richthofen arranged the various members under two divisions of Trias in the same way as in his treatment of the Vorarlberg rocks:—

Lias.	Upper Dolomite, Dachstein limestone, and Heiligkreuz strata.
Upper Trias.	Raibl marls. Schlern dolomite. St. Cassian marls. Cipit limestone. Wengen shales and tufaceous rocks. Buchenstein nodular limestone. Mendola dolomite. Virgloria limestone.
Lower Trias.	Campil sandstones, etc. Seis limestones. Gröden sandstones.

The superposition of the rocks, their surface extension, and the local variability in their development, along with other points of stratigraphical importance, are then carefully discussed. Excellent geological sections show the parallelism of the succession in the different lines of section. The occurrence of the augite porphyrite is described, with reference both to contemporaneous and intrusive flows.

Upon the basis of the tectonic structure, and the distribution and development of the formations, Richthofen tries to discover the historical succession of events during Triassic time in South Tyrol, and more especially to determine the elevations and subsidences of the sea-floor in that area. In opposition to Buch and Élie de Beaumont, Richthofen attributes most of the changes in the form of the ground, and also tectonic disturbances to slow crust-movements. He also discusses the formation of the dolomite masses (ante, p. 250).

Whereas Leopold von Buch had explained these masses as dolomitised limestone, chemically altered by the agency of magnesia vapours and volcanic discharges, Richthofen made the suggestion that not only the dolomitic masses, but also a part of the immense thicknesses of pure pelagic Triassic limestone in the southern Alps, had been constructed by reef-building coral polyps during periods of slow subsidence of the sea-floor. Richthofen pointed out how the irregular constitution of a sea-floor occupied by coral reefs would afford an explanation for many of the peculiar tectonic appearances and facies developments that are otherwise very difficult of comprehension. Richthofen's sub-division of the Trias in South Tyrol has been little altered. Stur, in 1868, showed that the Heiligkreuz strata were parallel with the upper part of the Raibl strata; and as the position of the Kössen strata became fixed, both these and the Dachstein limestone, so often intimately associated with the Kössen strata, were transferred from Lias to Upper Trias.

Until the year 1856 there was no known extra-Alpine equivalent for any of the zones of fossiliferous Triassic deposits above the Muschelkalk. Athough almost one thousand species of marine fossils had been described from St. Cassian, Raibl, Esino, and Hallstatt strata, there was not a single species amongst them which could with security be shown to occur in extra-Alpine deposits. The only basis of comparison between Alpine and extra-Alpine Trias had been afforded by the few fossil species common to Alpine and extra-Alpine Muschelkalk. The highest interest, therefore, attached to the publication of a memoir by Oppel and Suess "On the supposed equivalents of the Kössen strata" (*Sitz. ber. Akad. Wien*, 1866), wherein Avicula contorta and other Molluscan species in the Kössen beds were identified with species in certain passage-beds between the Triassic and Liassic strata in Swabia.

There could be no question regarding the stratigraphical position of the Avicula contorta strata in Swabia since they reposed conformably upon the upper red Keuper marls, and were conformably succeeded by the lowest Lias with Ammonites planorbis. Hence the determination of this definite palæontological zone in the Alps fixed the upper horizon of Alpine Trias, and gave a clue to the solution of the relations between the Trias and the Lias in the Alps. While stratigraphers were well satisfied with this new vantage-ground for

their work of surveying, palæontologists found matter for discussion in the faunal affinities of the Avicula contorta zone —whether the fossils indicated nearer relationship to the Keuper fossils below or to the Liassic fossils above them.

Alberti and Plieninger, the two leading Swabian authorities, thought them distinctly Triassic in character, and included the Avicula contorta zone or Bone-bed as the uppermost member of the Keuper; Quenstedt, after some hesitation, distinguished the fauna as an intermediate assemblage occurring in passage-beds and premonitory of the Lias. Oppel (1856), Sedgwick, Murchison, and the great majority of the Austrian geologists at that time assigned the Avicula contorta zone to the Lias; Emmrich, Merian, Studer, and Escher von der Linth placed it in Upper Trias. In France, geologists had long been familiar with the fossiliferous deposits between Keuper and Lias, as these are well exposed over a considerable tract of country on the east and south of the Central Plateau and in Lothringen. Leymeric had described them in 1840 under the name of *Infralias*, but many of the later authors grouped them with Trias. The same difference of opinion reigned in Great Britain; Brodie and Strickland (1842) regarded the passage series with the bone-bed as Liassic, whereas Agassiz (1844) and Buckmann, on the basis of the Fish and Plant remains, declared the series to be Triassic in character.

Oppel and Suess gave in their first memoir no expression of opinion regarding the Triassic or Liassic age of the beds; the *relative* stratigraphical position sufficed for their immediate purpose. But in 1859 Oppel contributed a special memoir, and stated that after tracing the extra-Alpine "Contorta-zone" into Luxembourg and France, he had come to the conclusion that the limiting-line between Trias and Jura should be *above* the "Contorta" strata and *below* the zone of Ammonites planorbis. Two years later this view was supported by Gumbel in his *Geognostic Description of the Bavarian Alps* (1861). Gümbel proposed to group the Kössen strata and the Dachstein limestone together under the name of *Rhætic Group*, from their development in the Rhætikon district of the Alps, and to regard this group as the uppermost division of the Alpine Keuper. At the present day most of the German and Austrian geologists follow Gümbel's suggestion; but in France the majority of the geologists retain the position and the name "Infralias," which was suggested by

Leymerie, and afterwards strongly advocated by Jules Martin in several able treatises (1860-65).

The next important advances in the knowledge of Alpine Trias were those made by Gümbel in the northern zone of the Alps. The volume cited above by Gümbel on the Bavarian Alps was accompanied by five geological map-sheets surveyed on the scale of 1:100,000, and by forty-two sections elucidating the geology of the Bavarian Alps. It was the work of a resourceful man with inexhaustible energy, an iron frame, complete mastery of the latest information in his subject, an unquenchable thirst for new facts, new discoveries, and withal possessed of a genius for stratigraphical problems. For fifty years C. W. Gümbel occupied a pre-eminent position amongst European geologists. As Director of the Bavarian Geological Survey he controlled a wide sphere of geological, mineralogical, and palæontological activity, and his own individual achievements are amongst the most remarkable in the history of Alpine geology.

Even in this first large volume by Gümbel, he unfolded his novel conception that there had been at one time a mountain-chain to the north of the present Alps, stretching from the south-west edge of the mountains and uplands of the Bavarian Forest westward as far as the central French plateau. Gümbel called this supposed earlier mountain-range the *Vindelic Chain*, and upon the hypothesis that it separated Lower Bavaria and the adjoining areas from the region of the existing Bavarian Alps, he explained the differences between the deposits of the Alpine and extra-Alpine Trias. Again, upon the hypothesis that the disappearance of the Vindelic Chain was in some way associated with the vast upheaval of the eastern Alps in Cretaceous and Tertiary epochs, Gümbel thought many of the complicated questions regarding the lithological composition and peculiar surface distribution of the "Flysch" and pebble-beds of the north Alpine slopes might find an explanation. Be that as it may, Gümbel's "Vindelic Chain" has received more countenance in the Alpine literature than usually falls to the share of the more daring flights of geologists.

A favourite theme with Gümbel was the determination of time-equivalents in the faunal succession displayed in the rocks of Lower Bavaria and those of the Bavarian Alps, and this tendency to emphasise the comparative aspect of Alpine and extra-Alpine deposits is apparent even in the nomenclature

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which he used. Although in all essential features he adopted the same succession of Alpine Trias which Richthofen had established in his memoir on Vorarlberg and North Tyrol, the names and divisions in Gümbel's work differ considerably from those used by all previous authors. All the Alpine deposits are arranged under the three German divisions—Bunter, Muschelkalk, Keuper, and the names given to the sub-groups are in keeping with the fundamental idea of parallelism. Gümbel assigns to *Bunter strata* the Werfen shales together with the salt and gypsum intercalations at Berchtesgaden, Hallein, and in the Salzkammergut; to *Muschelkalk* the Guttenstein limestones and the Virgloria limestone, from which Gümbel enumerates thirteen species identical with extra-Alpine Muschelkalk species; to *Keuper*, Gümbel assigns all the other Triassic strata as follows:—

Upper Keuper or Rhætic Group.	8. Dachstein limestone. 7. Strata with Avicula contorta (Gervillia strata or Kössen beds).
Middle Keuper or Main Dolomite Group.	6. Calcareous flags. 5. Main dolomite. 4. Rauchwacke.
Lower Keuper or "Lettenkohle Group."	3. Cardita strata of Pichler (Raibl strata of Richthofen). 2. Wetterstein limestone and Hallstatt limestone. 1. Partnach strata.

These sub-divisions, erected by Gümbel in 1864 on the basis of his Bavarian studies, have undergone two important modifications in subsequent researches. The "Partnach Strata" of Gümbel were afterwards identified by Wöhrmann as typical *Raibl sandstones and shales*. And the Hallstatt limestone, regarded by Gümbel as a local facies of the Wetterstein limestone, has been proved to be distinctly younger than the Wetterstein limestone.

The views of Austrian geologists regarding the Triassic sub-divisions in their territories were subject to great variations. From the year 1856, Pichler devoted himself with enthusiasm to the study of the Alpine Trias. In his first publication, in 1856, on the north-eastern limestone Alps of Tyrol, he had described above the Bunter sandstone a *Lower* dark-grey

Alpine limestone; above it, dolomite and Cardita strata; then *Upper* Alpine limestone (Wetterstein), succeeded by Gervillia strata and Lithodendron limestone. Three years later Pichler accepted Richthofen's divisions of Trias, and referred the Wetterstein limestone to its right position below the Cardita or Raibl strata, but advocated the view that the Wetterstein limestone and the Cardita oolites and marls were in interbedded stratigraphical relations with one another. In 1866 and 1867 Pichler gave a series of geological sections in which he made it appear that between the Wetterstein Dolomite and the Virgloria limestone there was a thick and diversified complex of arenaceous and argillaceous strata, dolomite beds and nodular limestone, which contained a fauna like that of the Cardita strata, and probably corresponded in North Tyrol to the St. Cassian fauna in South Tyrol. Pichler thus originated the idea that an "Upper Cardita" or "Raibl" series and a "Lower Cardita" or "St. Cassian" series could be distinguished normally above and at the base of Wetterstein limestone, but sometimes interstratified with it as equivalent facies.

About the same time, in 1866, another point was gained in the comparison between Alpine and extra-Alpine areas. Examples of two typical "Raibl" fossils—*Myophoria Kefersteini* and *Corbula Rosthorni*—were discovered by Sandberger in the lead-glance or galena bed of the Franconian "gypsum Keuper." It was thus ascertained that the *Alpine Raibl strata were contemporaneous with the gypsum and marls which immediately succeed the upper limit of the "Lettenkohlen" or Lower Keuper group in the extra-Alpine areas.* Careful observations had been made by Fötterle (1856) on the palæontological sequence of the Raibl strata in their typical development at Raibl; those were corroborated in 1867 by Suess, who differentiated the Raibl strata into three palæontological zones: the *Lower*, composed of black shales with numerous plant and fish remains; the *Middle*, composed of limestone beds with *Myophoria Kefersteini;* and the *Upper*, composed of marly limestone with *Myophoria Whateleyi*, *Ostrea montis caprilis*, *Pecten filosus* and Megalodon casts. Suess applied the name of *Torer strata* to the upper horizon. Two years later Stur expressed his view that the lower horizon was the equivalent of the Wengen strata.

In the summers of 1863 and 1864, special survey work in the north-eastern Alps was carried out by the Survey Department under the direction of Lipold and Stur, and was the

means of elucidating the coal-bearing Mesozoic deposits in Lower and Upper Austria. Up to that time these deposits had been collectively termed "Gresten beds," and assigned to the Lower Lias. Lipold and his colleagues in the survey, Hertle and Stelzner, showed, however, that although coal-seams occur in the Liassic "Gresten beds," the coal-seams at Lunz, Lilienfeld, Scheibbs, Gaming, Gössling, etc., occurred in a complex of strata whose fauna and flora were undoubtedly Triassic. Lipold gave the name of *Lunz series* to the sandy and shaly coal-bearing complex, and Stur, who worked out the flora of this series, identified it with that of the "Lettenkohle" in Franconia and Swabia. In the lower portion of the "Lunz series" *Posidonomya Wengensis* (a Wengen-Cassian type) and *Ammonites floridus* were identified; Hertle proposed to differentiate this horizon as *Reingraben shales*. The limestone beds below these shales were found to be rich in *Halobia Lommeli* and *Ammonites Aon*, and were distinguished as *Gössling strata*.

The diversified deposits of the Gössling, Reingraben, and Lunz groups pass gradually upward into purer limestone and dolomite beds, which received the local name of *Opponitz-limestone*, and were found to contain the characteristic Lamellibranch fauna of the upper or "Torer" horizons of the Raibl strata at Raibl. The continuity of the palæontological sequence in these horizons of Trias in the north-eastern Alps was the more important, as the succession of the strata containing them was held to be undisturbed, and therefore the order of the consecutive palæontological types in this locality was regarded as a safe standard for comparison in determining the age of the same faunas when they appeared in partial development in the scattered patches of fossiliferous deposits elsewhere.

Between the years 1865 and 1869, Laube published an admirably illustrated monograph of the St. Cassian fauna, and his identifications and nomenclature of the fossils corrected many errors which had been made by Münster and Klipstein. Laube emphasised the peculiar character of the St. Cassian fauna, pointed out the great difference between it and the much more highly-developed fauna of the Hallstatt limestones, and the strong resemblance between the St. Cassian and Raibl faunas.

In the summer of 1866, E. Mojsisovics von Mojsvár began his Triassic studies, which he has continued for more than thirty

years. His first geological tours were taken in the Salzkammergut in the companionship of his teacher, Suess, and at the close of the summer the two authors published a short communication in the Survey Reports on the Triassic succession between the lakes of Hallstatt and Wolfgang. Especial attention was given to the development of Rhætic and Jurassic formations in the Osterhorn mountains, near Lake Wolfgang. In connection with two sections in Königsbach and Kendelgraben, carried out with the most scrupulous accuracy, Suess demonstrated the fact that different lithological and palæontological developments predominated in the Rhætic group of adjacent localities, and gave the distinctive names of Swabian, Carpathian, Kössen, and Salzburg facies to the particular Rhætic series characteristic of the localities.

During the two following years Mojsisovics was engaged on the special investigation of the Alpine salt deposits. The results of his personal researches were set forth in a memoir entitled "On the sub-division of the Upper Trias formations in the Eastern Alps" (*Jahrb. k. k. geol. Reichsanst.*, 1869). This memoir attracted great notice at the time on account of many new views expressed in it.

In opposition to Gümbel, Mojsisovics thought it undesirable in those earlier days of Alpine research to compare Alpine and extra-Alpine areas, and to make this comparison a basis of the names that were to be applied to the Alpine rocks. He also advanced the opinion that the pelagic sediments of the Alpine Upper Trias included several distinguishable Cephalopod faunas, the lowest of which, with *Trachyceras doleriticus* and *T. Archelaus*, characterised the Partnach marls and shales and the siliceous and nodular beds with *Halobia Lommeli*, present both in Northern and Southern Alps. The second Cephalopod fauna, with *Ammonites Metternichi*, *Am. tornatus*, and numerous species of *Arcestes*, seemed to be limited to the Zlambach and the Hallstatt strata of the Salzkammergut. The next Cephalopod fauna included *Trachyceras Aonoides* and many other richly-decorated Ammonite species. Mojsisovics thought the most important palæontological line of division in the Alpine Upper Trias was that which separated the zone of *Ammonites Metternichi* and the zone of *Ammonites Aonoides*. He sub-divided the Alpine Upper Trias on the basis of these distinctive faunas into a Noric and a Karnic division, succeeded by the Rhætic group.

Mojsisovics drew up a parallel table of the Upper Trias succession as presented in six different localities of the Eastern Alps—the Salzkammergut, the North Tyrol Alps, the Lombardy Alps, the South Tyrol Alps, the Karnic Alps (Raibl district), and the ranges in the foreground of the Austrian Alps (Lunz district). The chief features of this sub-division, proposed in 1869, will be apparent from a comparison of the parallel columns for three of the "provinces":—

	Noric Alps (Salzkammergut).	North Tyrol Alps.	South Tyrol Alps.
Karnic Division	Calcareous flags with *Semionotus*, Dachstein limestone Wetterstein limestone	Seefeld dolomite Wetterstein limestone	Dolomia media Torer strata Schlern dolomite
		Cardita strata Lettenkohle plants Cardita strata with *Am. floridus*	St. Cassian strata: 1. *Am. Eryx* 2. *Cardita crenata* 3. *Am. floridus*
	Hallstatt limestone with *Am. Aonoides*, *Am. subbullatus*, etc.	Unfossiliferous limestone and dolomite	Wengen strata
Noric Division	Hallstatt limestone with *Am. Metternichi* Zlambach strata Reichenhall limestone	Unfossiliferous limestone and dolomite	Limestone and dolomite
	Salt deposit	Hasel and Reichenhall limestone	
	Partnach dolomite	Partnach dolomite (Arlberg limestone)	Limestone and dolomite
	Pötschen limestone	Partnach marls with *Corbis Mellingi* *Ostrea montis capsilis*, etc.	Siliceous limestone with *Halobia Lommeli*, *Am. Archelaus*, etc.
	Nodular limestone with Halobias	*Halobia* beds	

The above sub-division has several serious stratigraphical blunders, and cannot be regarded as an improvement on the previous attempts of Hauer, Richthofen, and Gümbel,

which, if less ambitious, were based upon accurate stratigraphical investigation of the locality taken as the type in each case. But in the new sub-division Mojsisovics assumed the most important palæontological limit to pass through the middle of the masses of limestone and dolomite where it was an impossibility to find any stratigraphical evidence of it. Nevertheless, the swing of the pendulum of Austrian research from the stratigraphical to the palæontological aspect of the succession was not without a distinct advantage. All through the Eastern Alps, in the villages and valleys, there were local collectors enthusiastically engaged in seeking and disinterring the booty of fossils for the Imperial Museum in Vienna; rocks were even quarried, and the greatest precaution taken to procure the Cephalopods in as complete a state as possible from the limestone and marble of the Salzkammergut.

New surveys were conducted by Mojsisovics in the Inn valley, the Kaiser mountains, and Karwendel mountains during 1869 and 1870, and the results of those induced him to make many important alterations on his former sub-division of Upper Trias in North Tyrol. Now the Lower Cardita or Partnach strata were placed by him beside the Partnach Dolomite as the representatives of the Noric division; then came Cardita strata again as the equivalent of St. Cassian strata; above that, the Wetterstein limestone; then a third horizon of Cardita strata corresponding to the Lower or Upper Raibl beds; and finally, the Main Dolomite as the Rhætic division. In the year 1873 Mojsisovics identified the Arlberg limestone in Vorarlberg with Partnach dolomite in North Tyrol and Bavaria, and contested the occurrence of Wetterstein limestone in Vorarlberg.

In 1874, after Mojsisovics had become personally acquainted with the South Alpine Trias, he contributed a memoir to the Austrian *Jahrbuch*, in which he developed his ideas regarding biological provinces in the Alpine seas during Upper Triassic eras, and the consequent local variations of rock-facies. He began by demonstrating the narrow geographical limits within which the Cephalopod fauna of the Noric division was confined between Berchtesgaden and the Leitha mountains, and explained the existence of a special fauna on the assumption that the area in question during the deposition of the Lower Hallstatt limestone and Zlambach strata had been almost completely shut off from the other parts of the Alpine Triassic sea.

He distinguished this particular biographical province as the *Juvavic Province.* According to Mojsisovics, the beginning of the era represented by the Karnic division of the Upper Trias was marked by the re-opening of a wider communication between the "Juvavic Province" and the much more extensive *Mediterranean Province* on the south and west of it; this view was based by Mojsisovics upon his identification of many species in the higher portions of the Hallstatt limestone, which enjoyed a wider distribution in the Triassic limestone and dolomite of the Eastern Alps.

Whereas Mojsisovics in his earlier works had not attributed much importance to the differences of facies which had been pointed out by Richthofen, Gümbel, and others, these relations were now fully appreciated and made a leading feature in his sub-division of the Trias. The Triassic zones were now defined quite independently of their lithographical characters, solely upon palæontological characteristics, and were sub divided according to their marine faunas:—

5. Rhætic Division		Dachstein limestone and Kössen strata.
4. Karnic Division	(*d.*)	Main Dolomite.
	(*c.*)	Raibl or Cardita strata.
	(*b.*)	Zone of *Trachyceras Aonoides.*
	(*a.*)	St. Cassian strata and the middle portion of the Hallstatt marble (zone of *Am. subbullatus*).
3. Noric Division	(*b.*)	Zone of *Daonella* (*Halobia*) *Lommeli* and *Trachyceras Archelaus* (Wengen strata, Lower Hallstatt limestone, Pötschen limestone, Partnach marls in part, and Wetterstein limestone).
	(*a.*)	Zone of *Trachyceras Reitzi* (Buchenstein strata in South Tyrol; Zlambach strata in North Tyrol).
2. Muschelkalk	(*b.*)	Zone of *Am. Studeri* and *Daonella Parthanensis.*
	(*c.*)	Zone of *Trachyceras Balatonicum* and *Retzia trigonella.*

1. Bunter sandstone, as in earlier sub-divisions, concludes with the Campil series of micaceous sandstones.

The sub-divisions ot 1874 certainly introduced several changes for the better; it cancelled the Lower Cardita strata and Partnach dolomite as independent horizons of deposit. It also recognised the Raibl strata in their true stratigraphical position below the Main Dolomite. In South Tyrol, Mojsisovics in 1874 assigned Raibl strata to a position *above* the Schlern dolomite and *below* the Main Dolomite. But in contrast to Gümbel and Emmrich, Mojsisovics expressed himself as an adherent of Richthofen's Coral-reef theory, and regarded it as the chief explanation of the facies differences. The "Schlern Dolomite" in South Tyrol, he said, represented the whole Noric and a part of the Karnic division, and in many places, for example, at the Mendel, at Latemar, and at Marmolata, the "Mendola Dolomite" facies replaced the Muschelkalk.

Five years later, in 1879, Mojsisovics published his memorable work on *The Dolomite Reefs of South Tyrol*, accompanied by six coloured geographical map-sheets (scale, 1 : 100,000). The general features of interest most prominently brought forward by Mojsisovics in this work were his support of the Coral reef theory, the significance ascribed by him to facies variations within narrow geographical confines, the corroboration which appeared to be given by numerous geological sections prepared in South Tyrol and Venetia to the sub-division of the Trias erected by the author in 1874, and the more definite boundaries ascertained for the Juvavic and Mediterranean provinces of East Alpine Upper Trias.

The systematic collection of fossils in all parts of the Eastern Alps, which Mojsisovics had been mainly instrumental in initiating, resulted in the accumulation of a vast store of fossil material in Vienna. Again, there was one drawback, that as the atmospheric weathering of fossils is an extremely slow process, the first rich gathering of fossils was in many cases picked up on the spot by the local village collectors, who could not all be equally capable of remembering, amongst the hundreds that were collected, the precise locality for each individual fossil form. And when the geologists from Vienna afterwards wished to be informed, there were loopholes of error that could not always be controlled. At the same time, in Vienna, numerous monographs of Alpine fossil forms were being prepared and published, and displayed such wonderful beauty and diversity in Alpine faunas that the palæontologists of all lands looked with admiration at the plates in the Vienna monographs.

The work that has been done by Mojsisovics in the description of the Cephalopods, both in the Juvavic Province or Salzkammergut (1873-93) and in the Mediterranean Province (1882), is an achievement of permanent value and general scientific interest. The unusually narrow limits assigned by Mojsisovics to each genus and specific form increases the difficulty of subsequent identification of other specimens, and has been often a cause of complaint. Unlike Thomas Davidson, the founder of the systematic knowledge of Brachiopods, who left it to posterity to break up his broadly-defined, well-marked genera and species into several, if it were found practicable and desirable (cf. p. 400), Mojsisovics, who has been the chief exponent of Triassic Cephalopods, has founded a system distinguished by the extreme differentiation of its types. But, whatever may be the ultimate verdict of posterity on the system, the work has been so excellently produced that it confers an imperishable boon both on Alpine geology and zoological knowledge.

There can be no doubt that the keen palæontological sense of Mojsisovics and his subtlety in the differentiation of fossil forms so biassed his mind that, during his surveys in the field, he undervalued the possibility that other causes than facies developments might have produced the local peculiarities in the appearances of the Triassic succession. The tectonic disturbances caused by the repeated crust-movements in Alpine areas did not receive at the hands of Mojsisovics a treatment commensurate with their great significance. And from the year 1866, when the memoir on the geology of the Hallstatt area was published under the combined authorship of Suess and Mojsisovics, the stratigraphical results obtained by Mojsisovics were frequently called in question by other geologists.

Stur, in 1866, objected to the position assigned by Mojsisovics to the salt deposits and Hallstatt limestone. The hydraulic limestones and marls (afterwards the "Zlambach strata" of Mojsisovics) near Aussee covers the salt deposits of that area; in these limestones Stur had found corals, and close beside them Ammonite species identical with those in the Hallstatt limestone. Again, in certain shales below the salt deposits of Aussee, Stur had found Halobia Lommeli, a typical species of the "Buchenstein" or upper horizon of the Alpine Muschelkalk in South Tyrol, and of the Gössling series

in the Lunz facies. Stur, who had identified the Halobia Lommeli horizons in the lower Austrian Alps conformably *below* the Lunz series, concluded that the Zlambach strata and the salt deposits were in the main the equivalents of the Lunz series (*ante*, p. 483). But in this case, as part of the Lunz series had been proved palæontologically to be the equivalent of the more prevalent "Raibl" facies, Stur concluded that part of the Hallstatt limestone must be the equivalent of the "Main Dolomite" facies of Upper Keuper in North Tyrol and Bavaria. This was a much higher stratigraphical position than Mojsisovics assigned to the Hallstatt limestone in his publications of 1866 and 1869 (see Table on p. 485).

In 1871, in a work entitled *The Geology of Styria*, Stur gave an exposition of the Triassic succession in that area which had the advantage of being founded wholly upon his own personal field observations, and which likewise carried out the comparative aspect of Alpine and extra-Alpine deposits so strongly recommended by Gümbel. The Upper Trias or "Keuper" divisions were thus determined by Stur for the Styrian district, and compared with other Alpine facies:—

EXTRA-ALPINE.	IN STYRIA.		IN OTHER EAST ALPINE AREAS.
	Opponitz Dolomite.		Main Dolomite and Upper Hallstatt limestone.
Upper Keuper.	Opponitz Limestone		Torer or "Upper Raibl" horizons. Heiligkreuz strata near St. Cassian. Red Schlern strata at the Seis Alpe. Lower Hallstatt limestone near Ausee.
Lower Keuper.	"Lettenkohlen" Group and Salt Deposits.	*b.*	Lunz and Reingraben strata; Partnach, Cardita, and Bleiberg strata; the middle "Raibl" horizons with *Myophoria Kefersteini*, and the St. Cassian strata.
		a.	Widely-distributed occurrence of Wengen shales with *Halobia Lommeli*.

The chief error in Stur's sub-division of Trias was his removal of the salt deposits from their association with Lower Trias to a place in the much higher Keuper series.

Gümbel, in 1873, wrote a paper *Das Mendel und Schlern Gebiet*, which was published in the reports of the Bavarian Academy of Sciences. Gümbel proved that the Mendola dolomite in its development at the Mendel corresponds, as Richthofen had stated, to the Muschelkalk dolomite with *Gyroporella pauciforata* in the typical section of the Pufls ravine, but that the higher horizons of the Mendola dolomite at the Mendel correspond with Schlern dolomite. Gümbel contended, therefore, that the name of "Mendola dolomite" was unnecessary. The Buchenstein strata are absent at the Mendel, but at the Schlern and Seis Alpe area they are present and are succeeded by shales (pietra verde) containing *Halobia* and *Posidonomya Wengensis;* above these shales, Gümbel distinguished in ascending order the St. Cassian strata, the Schlern dolomite, the red Raibl marls and thin-bedded series of the Schlern plateau. Gümbel erroneously compared the "Buchenstein" horizons in South Tyrol with the "Partnach" horizons in North Tyrol, and consigned both to the period of Upper Muschelkalk. In Gümbel's work the Lettenkohlen or Lower Keuper group was said to be represented in South Tyrol by the St. Cassian series, or its dolomitic facies.

Gümbel strongly insisted that the Schlern dolomite was a stratified marine deposit, originally calcareous, and rich in *Gyroporella;* that it had extended over a considerable part of South Tyrol, and was not a coral-reef structure. Gümbel identified the Raibl strata of South Tyrol with the Upper Cardita strata in South Tyrol, and agreed with Sandberger that they were the Alpine facies of the lower horizons in the extra-Alpine "gypsum Keuper." He still, however, adhered to the independent existence of Lower Cardita strata in North Tyrol as a fossiliferous zone below Wetterstein Limestone in that area.

In 1874, Von Richthofen published in the *Zeitschrift* of the German Geological Society a reply to Gümbel's various points of attack on his work in South Tyrol. Richthofen admitted that he had overlooked the identity of the upper part of the Mendola dolomite with Schlern dolomite, but nevertheless held that, as the two horizons of dolomite were palæontologi-

cally distinct, both names should be retained. He also answered all objections that had been made by Gümbel to his application of Darwin's Coral-reef Theory in explanation of the calcareo-dolomitic masses of rock, and re-stated the theory on even firmer and broader grounds. In the same journal, during 1874 and 1875, two articles appeared by H. Loretz, affording a careful review of all the opposing considerations advanced by Gümbel, and confirming them upon the basis of his own observations in the border districts of South Tyrol and Venetia.

The publication of the combined researches of the Austrian Survey in the latter region (Mojsisovics' *Die Dolomit-Riffe*, etc.) in 1879, brought forward many new data, and presented an apparently complete corroboration of Richthofen's view that the calcareo-dolomitic masses represented coral reefs, constructed locally in the Upper Triassic seas of South Tyrol. So convincing an impression did this work create that the Reef Theory was accepted and explained in the geological text-books. The matter rested there for nearly twenty years, when it was again brought under detailed examination by Miss M. Ogilvie, whose first paper on the stratigraphy of various areas in South Tyrol appeared in the *Journal of the Geological Society of London*, and was supplemented by a full critical discussion of the coral-reef theory, adverse to its application to the dolomites (*Geolog. Magazine*, 1894).

The Esino limestone of the Lombardy Alps was made a special subject of research by Benecke, and the contributions by this geologist have successfully demonstrated the age and stratigraphical relations of this southern facies of the Alpine limestone (*Geogn.-Paläont. Beiträge*, 1876, and *Jahrb. für Mineralogie*, 1884-85). Benecke showed that the fauna of the Esino limestone, described by Stoppani, everywhere lay below the fossiliferous Raibl horizons. Mojsisovics in 1880 confirmed Benecke's results, and stated that the Esino limestone in the Val di Lenna directly succeeds the upper Muschelkalk; near the Lake of Como it succeeds the Perledo fish-shales, and is surmounted by Raibl strata. According to Mojsisovics, the Cephalopod fauna of the Esino limestone indicates the contemporaneity of the limestone with the more diversified Wengen-Cassian facies in South Tyrol. This short but important memoir by Mojsisovics has been followed by a large number of special contributions in more recent years.

In addition to the writings of T. N. Dale (1876), G. Curioni (1877), and Lepsius (1878), on portions of the Lombardy Alps and Etsch Valley, Benecke has done much valuable work in the vicinity of Lake Garda, the Adamello Massive and Judicarian Alps, and Bittner has contributed excellent stratigraphical accounts of the complicated Judicarian district (1879-83), and the neighbourhood of Recoaro (1883). Amongst the most important palæontological contributions are ranked the monographs by Kittl, J. Böhm, and Koken on the Triassic Gastropods of South Tyrol, by Bittner on the Brachiopods and Lamellibranchs, and the monograph by Salomon on the stratigraphical relations and the fauna of the Marmolata Mountain (*Palæontographica*, 1895).

In the Northern Alps there has continued the greatest insecurity about the true position of the Hallstatt limestone and the parallelism of Partnach strata and the various horizons of Cardita strata. A geological investigation of the Karwendel mountains was commissioned by the German and Austrian Alpine Club, and was excellently carried out under the direction of Rothpletz by several members of the Munich School of Geology. The results, published in 1888, showed that typical "Cardita" strata lie below the Main Dolomite of North Tyrol, and their fauna undoubtedly differs from the Partnach strata which underlie the Wetterstein limestone and contain *Koninckina Leonhardi*, typical St. Cassian fossils.

Almost simultaneously with the publication of these results, Wöhrmann showed that the plant-bearing sandstones near Partenkirchen, which had been relegated by Gümbel to Partnach strata, were layers interbedded with the upper Cardita or Raibl deposits. Skuphos traced the development of the Partnach strata through a considerable region, and showed that they continually form the basis of the Wetterstein limestone, and exhibit sometimes a marly, sometimes a calcareous lithological character. As Fraas had said in 1893, in his admirable description of the geology of Wendelstein Mountain, the fossils of the Partnach strata have the closest resemblance to the fauna of St. Cassian or to that of the Reiflinger strata in North Tyrol, and are best regarded as Upper Muschelkalk.

Skuphos contended that the Lower Cardita strata of Pichler were palæontologically identical with Raibl strata; and

Wöhrmann had previously shown that in all the places where former writers believed Lower Cardita beds to be present, they were Upper Cardita beds which had been faulted to a position below the Wetterstein limestone as a result of crust-movements.

Wöhrmann devoted himself for several years to a thorough and comprehensive systematic research of all the "Cardita" and "Raibl" deposits in the Northern Alps and worked out their stratigraphical relations, both by means of geological sections and of comparative palæontological studies. He concluded by sub-dividing "Raibl" deposits in three distinct palæontological groups, the lower and middle containing many species identical with the Wengen-Cassian forms, while the upper agrees with the Torer or upper horizons of the fossiliferous series near Raibl. Wöhrmann included the rauchwacke and gypsum beds in Vorarlberg, the Opponitz limestone in Austria, the Torer strata and Megalodon dolomite in the Southern Alps with the *Upper Raibl* horizons; the Lunz and Reingraben strata, red Schlern plateau strata, and the shaly limestone containing *Myophoria Kefersteini* with the *Middle Raibl;* the shales with *Trachyceras Aon* and *Halobia rugosa* with the *Lower Raibl* division.

Wöhrmann has thus combined the whole palæontological sequence of Wengen-Cassian and Raibl deposits under the one name of "Raibl deposits," and used the name in the wide sense in which it was originally applied at Raibl by Fötterle, Suess, and Stur (*ante*, p. 472). But as the St. Cassian fossils were discovered and described before those of the Raibl strata, the adoption of the latter name generally for the group in the Alps seems scarcely legitimate. The Alpine Raibl deposits are regarded by Wöhrmann as the equivalent of the extra-Alpine Lettenkohle group, while he holds the Wetterstein limestone and its equivalents to be the equivalents of the uppermost horizons of German Muschelkalk.

With the exception of Stur, the older Alpine geologists had placed the Hallstatt limestone of Salzkammergut as an equivalent of the Wetterstein limestone in Bavaria and North Tyrol in the lowest division of the Upper Trias. The second edition of Hauer's Geology of Austria-Hungary still gave this interpretation of the Hallstatt limestone, and separated the Kössen beds, Dachstein limestone, and Main Dolomite from the Triassic system, regarding them as an independent

Rhætic formation. Mojsisovics, who had in 1869 placed the Hallstatt limestone partly in his Noric and partly in his Karnic division of the Trias, shortly after discovered *Ptychites Studeri* and other Cephalopod species characteristic of Alpine Muschelkalk in red marble and limestone on the shores of the Lake of Hallstatt. Further discoveries near Hallein and Serajewo established a considerable extension of this facies of Upper Muschelkalk. To the same horizon Mojsisovics referred the Muschelkalk strata of Sintwang near Reutte, the Triassic Cephalopods of the black limestone in the Himalayas, and a number of Ammonites from Spitzbergen and Eastern Siberia, which have been described in monographs. The Hallstatt fauna was also found in Transylvania in 1875 and afterwards in California and other localities, hence it became abundantly clear that the name of "Juvavic Province" was no longer suitable for the Hallstatt area, since the characteristic fauna, instead of having been confined to a small area in the Austrian Alps, had apparently been widely distributed in the vast ocean of the Upper Triassic epoch. Correlatively, the "Mediterranean Province" lost its value, and Mojsisovics in 1892 found it necessary to give up these supposed biological provinces of the Alpine Trias.

Bittner had made considerable collections of fossils in the limestones of the Hagen mountains, the Hohe Göll, and at Hernstein in Lower Austria. After examination of these fossils in 1882 and 1884, he recognised the fossiliferous limestones in which they occur as interbedded in the Dachstein and Main Dolomite series. From the fossil resemblances Bittner supported the opinion of Stur that the Hallstatt limestone was an equivalent of the Dachstein limestone and Main Dolomite. Mojsisovics verified Bittner's observations and at the same time stated that the so-called Zlambach strata were only argillaceous, lenticular intercalations in the "Noric" Hallstatt limestone. But as the supposed position of the Zlambach strata at the base of the Hallstatt limestone had been the security previously given for the inclusion of part of the Hallstatt limestone in the Noric division, the position of that portion of the limestone was now rendered doubtful. Mojsisovics thereupon transferred the "Noric limestones" of his earlier systematic arrangement of Upper Trias (cf. p. 487) to a position *above* the Karnic division. The name of "Juvavic," which had proved

inapplicable as the designation of a biological province, was used by Mojsisovics for the new palæontological zone of Alpine Trias which he now interposed above the Karnic division

According to this new interpretation offered by Mojsisovics, the "Karnic" division of Hallstatt limestone with *Am. Aonoides*, etc., is the equivalent of the Dachstein limestone and Main Dolomite above the Raibl strata in many parts of the Alps; the "Juvavic" limestones follow, and their upper limit is determined by the Rhætic horizon. Mojsisovics also removed the salt deposits, the Reichenhall strata, the Pötschen limestone, and the Partnach dolomite from the Noric division, so that there remained in this division only the nodular limestones, with *Halobia Lommeli* and a very scanty fauna.

Bittner protested against the erection of a "Juvavic" division, contributing a series of articles on the subject to the publications of the Austrian Survey or issuing them independently. The attitude assumed by Bittner was that the name of "Noric Division" was in the first instance introduced for the Hallstatt limestone strata with *Am. Metternichi*, and ought to be retained for these limestones, although in the light of the more recent researches it would have to be placed above the Karnic division in the stratigraphical succession. The controversy became more and more personal, and was all the more unfortunate for the literature, as the adherents of Mojsisovics and of Bittner used the term "Noric Division" to signify quite different horizons of Upper Trias. Bittner then proposed to apply the name of "Ladinian" to the division below the Karnic and to comprehend in it the nodular limestones, the Wengen-Cassian series, the Schlern dolomite, Esino limestone, and Wetterstein limestone. Thus Bittner's suggestion was to recognise in ascending order Ladinian, Karnic, and Noric Divisions of Upper Trias. But Mojsisovics quite recently, in 1898, agreed at the instance of Suess, Diener, and Hoernes, to discard entirely the term "Noric" and let the division fall, recognising only a Lower or Karnic Division and an Upper or Juvavic Division of the East Alpine Upper Trias.

By the discovery of rich fossil localities in the Triassic rocks of the Himalaya and the Salt Range, the pelagic Triassic deposits of Eurasian areas began to be classified from a wider

standpoint. The palæontological sequence established in the Alps was applied to the Himalayan development of Trias with a few slight modifications. Waagen, Diener, and Mojsisovics, who investigated the Eastern faunas, divided the whole of the Triassic system into four series (Skytian, Dinarian, Tyrolean, and Bajuvarian), further sub-divided into eight groups, fifteen sub-groups, and twenty-two zones.

At the present time, the general succession of the Alpine Trias may be said to be fairly definite, but there is still some variance of opinion regarding the parallelism of the Alpine and extra-Alpine divisions. For example, there is no certainty yet where the Alpine Muschelkalk may be said to end and the "Lettenkohlen" group to begin; whether the Wetterstein, Esino, and Marmolata limestones and the St. Cassian strata may be referred to the uppermost horizons of Muschelkalk or regarded as members of the "Lettenkohlen" group in the Alps; again, whether the Lunz and Raibl strata in the Alps correspond to the "Lettenkohlen" group or the lower Gypsum-Keuper in the extra-Alpine development of Trias.

G. *The Jurassic System.*—In the very beginning of the nineteenth century the fundamental features of the Jurassic succession had been so securely established by William Smith that subsequent observers had little to amend. The Jurassic deposits have attained a remarkably typical and perfect development in England. No serious obstacles of any kind are interposed in the path of the observer; no great tectonic disturbances, foldings, fractures, or high inclinations of the strata; no sudden changes of facies, and no gaps in the sedimentary series. The straightforward aspect of the stratigraphical relations, together with the characteristic lithological development of each individual member of the series, and the extraordinary wealth of fossil remains, has rendered England the classic ground of the Jurassic system.

William Smith at first treated the successive strata as equal in rank, and although he afterwards (1815 and 1817) united them into groups, these were not well defined and underwent modifications before they were received into the literature. Conybeare and W. Phillips comprised under the name of Oolitic series all the strata between the ferruginous sand (lowest Cretaceous) and the red marl (Triassic). The same geologists classified the Lias as an independent basal forma-

tion in the Oolitic series; and sub-divided the Oolitic formation above the Lias into three groups—the *Lower Oolites*, beginning with the marly sandstone and concluding with the Cornbrash; the *Middle Oolites*, embracing the rocks from the Kellaways sandstone to the Coralrag; the *Upper Oolites*, embracing the rocks from the Kimmeridge Clay to the Purbeck marls and limestones.

A local monograph on the geology of the Yorkshire coast, published in 1822 by Young and Bird, contributed many valuable observations and good illustrations of the characteristic fossils in this area. But a much more important work on the geology of Yorkshire was published by John Phillips in 1829. This excellent observer, who had been trained by his uncle, W. Smith, demonstrated the presence in Yorkshire of many of the strata known in the south-west of England. By means of geological sections, he established their exact succession, enumerated the fossils characteristic of each group, and gave drawings of the leading types. Various memoirs by De la Beche, Buckland, and Sedgwick appeared between 1822 and 1835, and supplied accurate information regarding the Oolitic and Liassic deposits on the south coast of England. Lonsdale in 1829 investigated the vicinity of Bath. In 1836, an admirable monograph was published by Fitton on the Upper Oolites and the layers immediately succeeding them in the Isle of Wight and the south coast of England. Fitton separated the Purbeck beds from the Upper Oolites and combined them with the Weald Clay and Hastings sandstone as an independent *Wealden Formation* between the Oolitic and the Cretaceous deposits.

De la Beche had pointed out in 1822 that the Oolitic and Liassic formations of the south coast of England reappeared again in Normandy, and Roger and Fitton subsequently demonstrated that the whole succession was present in the neighbourhood of Boulogne-sur-Mer, with a lithological development almost identical with the English. In 1825 and 1829 De Caumont wrote valuable memoirs on the Normandy Oolites. He described and showed in geological sections the Normandy succession of the Kimmeridge group, the Coralrag, Lower Calcareous Grit, Oxford Clay, Cornbrash, Forest Marble, Great Oolite, Fullers' Earth (Argîle de Port en Bessin), Lower Oolite, and Lias. He also drew attention to the occurrence of a complex of strata then unknown (cal-

caire de Valognes) between the Lower Lias and the Trias, which afterwards proved to be in part an equivalent of the Rhætic series.

While it was comparatively easy to determine the parallelism between the succession of Oolite deposits in the North of France and the succession in England, it was a much more difficult matter to compare the German and Swiss deposits of the same age with the English types. In 1795, when Humboldt travelled through Bavaria and Switzerland on his way to Upper Italy, he described a thick series of limestones "between the old Gypsum (of the Zechstein formation) and the newer sandstone (Bunter sandstone)," both in the Franconian Alps and the Swiss Jura Chain, and he applied the name of "Jura Limestone" to this massive development. Ami Boué in 1829 defined the stratigraphical position of the "Jura Limestone" more accurately; he limited the term to the limestone above the Lias and below the Wealden formation. In the same year Brongniart had selected the term *Terrain Jurassique* for the sedimentary deposits comprised within almost the same limits. Rengger, also in the same year, contributed a memoir on the "Aargau Jura," under which name he comprised all the rocks between the Bunter Sandstone and the Molasse —practically all the Mesozoic rocks and the older Tertiary. Rengger's section through the Aargau Jura shows that he never understood the repetition of strata caused by tectonic disturbances, and he assigned each recurrence of the typical limestones to a younger geological epoch.

Similar views were shared by Merian when he first wrote on the Swiss Jura mountains; but as his investigations continued, he explained the repetitions of certain strata as a result of the curvature of the crust. An important work by E. Thirria on the Jura of the Haute Saône showed that in the French Jura Chain the Lias was succeeded by a richly diversified complex of strata, which Thirria, in accordance with Brongniart's suggestion, called "Terrain Jurassique" and arranged in a number of sub-divisions. These were compared with the English sub-divisions on the basis of the identification of the fossils by Voltz. The literature, however, was not yet sufficient for an exact comparison of the fossils, and although the attempt was well planned, there were several palæontological blunders. The four chief divisions of Thirria were as follows:—

Sub-div. 4. About 40 feet of ferruginous clays for which Thirria could not find an English equivalent. (These were Tertiary deposits, erroneously included by Thirria with the Jurassic formation.)

Sub-div. 3. Over 200 feet of rock corresponding with the Kimmeridge Clay and Portland Stone, but exhibiting in the upper horizons a lithological and palæontological development different from the English.

Sub-div. 2. About 350 feet of rock corresponding with the Kellaways Rock, Oxford Clay, and Coralrag in England.

Sub-div. 1. About 270 feet of rock including five well-marked horizons palæontologically comparable with the Inferior Oolite, Fullers' Earth, Great Oolite, Forest Marble, and Cornbrash of the English series.

The memoir by Thirria was one of the best of the older publications on Jurassic deposits, although it gave no information regarding the tectonic structure of the area examined. It was soon over-shadowed by the greatness of Thurmann's tectonic and orographical studies in the western part of the Swiss Jura mountains. The original ideas formulated by the geologist of Porrentruy regarding the processes of mountain-making have already been mentioned (p. 302). In two memoirs, published 1832 and 1836, Thurmann gave an admirable exposition of the stratigraphy of the Bernese Jura. Voltz in Strasburg rendered willing assistance in identifying the fossils and determining the parallelism of the rocks with foreign equivalents.

Thurmann distinguished the following sub-divisions in the Terrain Jurassique :—

C. *Upper Jurassic or Portland Group.*

15. Portland Limestone with *Exogyra virgula*, etc.
14. Kimmeridge Marl of Le Banné, very fossiliferous (*Exogyra virgula*, *Pteroceras Oceani*, *Mytilus Jurensis*, etc.).

B. *Middle Jurassic.*

(*b*) Corallian group.

13. Astarte Limestone.
12. Nerinea Limestone.
11. Coral Oolite.
10. Coral Limestone.

(*a*) Oxford group.

9. Terrain à chailles.
8. Oxford Clay and Kellaways Rock.

A. *Lower Jurassic or Oolite Group.*

7. Dalle nacrée (= Cornbrash ?).
6. Calcaire roux sableux (= Forest Marble ?) with *Ostrea Knorri.*
5. Great Oolite (*Plagiostoma elongata*, etc.).
4. Marls with *Ostrea acuminata* (= Fullers' Earth ?).
3. Compact Oolite.
2. Ferruginous Oolite.
1. Grès superliasique (marly Sandstone).

Terrain Liasique.—The works of Merian, Thirria, and Thurmann were supplemented by Count von Mandelslohe's memoir entitled *Sur la Constitution géologique de l'Albe du Wurtemberg* (1836). Mandelslohe contributed several good geological sections, and drew a careful comparison between the palæontological sequence of the deposits in the Swabian Jura and that exhibited in the Jurassic deposits of England, Switzerland, and France.

Dufrenoy and Élie de Beaumont commenced their investigations on the French Jurassic deposits in 1825. The more important results were communicated in several memoirs, which were then published collectively in four volumes in the year 1838. Ten years later a comprehensive account of the "Terrain du calcaire Jurassique" was given by the same two authors in elucidation of the geological map of France. This was for several decades the standard work on the Jurassic deposits of France. Dufrenoy and De Beaumont defined and sub-divided the "Terrain Jurassique" of France precisely after the model of the English authors. They succeeded in demonstrating the parallelism of all the main sub-divisions in the French and English developments of the series, and introduced into French

geology the English nomenclature: Calcaire Portlandien, Argîles Kimmeridgiennes and Oxfordiennes, Coralrag, Cornbrash, Grand Oolite, etc. At the same time they varied the English nomenclature on certain points where the French development differed in any marked degree from the English.

The *General Survey of the Orographic and Geognostic Relations of North-Western Germany*, a work published in 1830 by Friedrich Hoffmann, described the Jurassic succession in that district in greater detail than a previous contribution by Hausmann (1824). Roemer, Koch, and Dunker made the German Jurassic fossils the subject of palæontological monographs, and their results, taken in conjunction with the geological map and sections of Hoffmann, showed that the equivalents of the English Jurassic formations were well represented in North-Western Germany. Thus it seemed as if the English development of the Oolitic and Liassic formations could be regarded also as a standard for the leading features of the *Terrain Jurassique* in France, Switzerland, and North Germany.

While it was Thurmann who provided the clue to the stratigraphy and tectonic structure of the Bernese Jura mountains, to Gressly belongs the credit of having for the first time elucidated the lithological and palæontological variations displayed in adjacent localities by deposits of the same geological age. Gressly was the founder of the teaching regarding rock facies, which afterwards played such an important part in the unravelling of Alpine stratigraphy.

In his investigation of the Solothurn Jura, Gressly[1] did not confine himself to the determination of the chronological succession of the Jurassic sub-divisions, but traced the horizontal extension of the different members. He soon became convinced that each particular petrographical develop-

[1] Amanz Gressly, born 1814 in a remote valley near Laufon, in the Jura mountains (Canton Solothurn), was intended for the Church, and studied in Solothurn, Lucerne, Freiburg, and Strasburg. Stimulated by his social intercourse with Voltz, Thirria, Thurmann, and Agassiz, he devoted himself exclusively to geology, and especially to the research of the Jura mountains. From 1840 to 1850 he geologised in the Solothurn Jura region; he supplied himself with means by the occasional opportunities of delivering expert opinion, drawing up technical estimates, etc. In 1859 he was sent by his patron Desor to Cette, where he studied the mode of life of marine organisms. In 1861 he took part in the Berna Expedition to the North Cape and Iceland; he died in 1865.

ment of facies of a geological horizon was characterised by a particular kind of fauna, and that certain genera and species, however frequently they might occur in some lithological deposits, were entirely excluded from rock-deposits of the same age, but with a different lithological constitution. Gressly described in great detail the various forms of rock-facies which occur in the Solothurn Jura (mud facies, coral facies, sponge facies; pelagic, sub-pelagic, littoral facies, etc.), named the fossil types which were characteristic of each, and judging both from the mineral constitution of the rocks and the fossil organisms contained in them, he drew conclusions regarding the mode of origin of the respective rock-formations.

The differences between littoral deposits, shallow-water and deep-sea deposits were distinguished, and also the variations exhibited by deposits accumulated in the open ocean, or in partially enclosed basins. Examples were likewise given of transitional or passage beds in areas connecting any two characteristic facies-developments. On the whole, Gressly found that the facies variations in the Solothurn Jura were insignificant in the Triassic, Liassic, and older Oolite deposits, but were extremely important in the Middle and Upper divisions of the Oolitic series. (*Observations géologiques sur le Jura Soleurois*, 1838-40-41.)

By a remarkable coincidence, a French geologist arrived theoretically at views closely resembling those demonstrated by Gressly in the field. Constant Prévost, in 1838, contributed an article to the Bulletin of the French Geological Society, which had special reference to a previous memoir by Prestwich. Prévost explained how in each geological epoch there must be contemporaneous deposits of pelagic, littoral, fluvio-marine, fresh-water, and terrestrial origin, replacing one another locally. Hence the mere lithological character of a rock-deposit could never determine its geological age. Prévost also elucidated the correlation of the faunal types with the various kinds of deposit. Calcareous deposits would, he said, always contain other forms of organic life than arenaceous or argillaceous deposits; on the other hand, deposits of the same lithological character, although of different geological age, might contain very similar fossil types. As an example of the varying constitution of contemporaneous deposits Prévost cited the coarse limestone, the siliceous limestone, and the gypsum of the Paris basin; while he illustrated the occurrence

of similar fossil remains in deposits of different geological age but the same lithological character, by referring to the lignite formations below and above the coarse limestone of the Paris basin and in the Isle of Wight.

Gressly was so strongly impressed with the variability of rocks considered in horizontal succession that he discountenanced the prevailing endeavour to identify in all the other European areas the same palæontological and lithological sequence as had been established for England. In his opinion this fallacious method was preventing the foreign geologists from arriving at a true conception of the characteristics of the Jurassic succession in their own countries.

The continental study of the Jurassic system received a new impulse when Leopold von Buch published his remarkable memoir, *On the Jurassic Rocks in Germany* (1839). In short, clear sentences Leopold von Buch sketched the extension and the orographical character of the South German Jura. Above the Lias, which spreads everywhere below the higher Jurassic rocks, the northern edge of the Swabian and Franconian Alp ascends sharply from the plains in front. Isolated Jurassic hills rise amid the plain like island masses. This peculiar configuration, in Buch's opinion, is not a result of a subsequent movement of elevation or of advanced denudation, but is associated with the conditions under which the Jurassic rocks originated. He *compared the present configuration with the steep outer slope of a coral reef, and expressed his conviction that the Swabian-Franconian Alp represents the remains of such a reef.*

The tectonic disturbances, foldings, and anticlines in the Swiss Jura were said by Buch to have been connected with the Alpine upheaval; the origin of the Franconian Dolomite was traced to the occurrence of a crust-rupture extending parallel with the Bavarian Forest, into which, according to Buch, subterranean magnesia vapours escaped, and by chemical interchange the white limestone in the neighbourhood was converted into dolomite.

Buch sub-divided the South German Jurassic deposits into three chief groups:—

3. Upper or White Jura.
2. Middle or Brown Jura.
1. Lower or Black Jura (Lias).

A short description of each group was given by Buch, and a comparison drawn between the South German strata

and those of similar age in England and France; at the same time Buch expressly stated that in consideration of the many contrasts presented by the South German facies, both palæontologically and lithologically, it is very undesirable to attempt to apply the English nomenclature. It was shown that the three leading groups might be again sub-divided into a number of palæontological zones characterised by certain definite leading fossil types ("Leitmuscheln"). Buch concluded this interesting work by an enumeration of one hundred and two carefully described species of the "leading molluscan types" characteristic of the successive rock-horizons.

The foundation was thus laid for the geology of the Swabian and Franconian Jura by Buch, but the main structure was built up by F. A. Quenstedt in after-years in his memorable treatise *Das Flötzgebirge Würtembergs* (1843 and 1851). The three chief divisions of Buch are sub-divided into sub-groups and zones according to their petrographical development and palæontological features, and the zones are distinguished by letters of the Greek alphabet. In this way the Lias and the brown and white Jura are each of them resolved into six zones, the oldest of which is designated as α, the youngest as ζ. Quenstedt's eighteen zones of the Würtemberg development of the Jurassic system have since shown themselves to be well founded, although they are not all of equal palæontological value. Clearly Quenstedt, for the sake of symmetry in the number of zones, defined some of them within rather narrower limits than others.

It was a great deficiency in Quenstedt's work that he had made no attempt to describe the tectonic structure of the area, or even to show by maps or sections the stratigraphical mode of occurrence of the strata. In 1853, Quenstedt remedied this by publishing a typical geological section of the Swabian Jura carried out by his pupil W. Pfizenmayer (*Zeitsch. d. d. geol. Ges.*, Taf. xvi.).

The work, however, which gave Quenstedt a pre-eminent place in the roll of fame was that which appeared in 1858 under the simple title of *Der Jura*. In it Quenstedt gave a marvellously attractive exposition of the results of his nineteen years' researches on this formation; the description and illustrations of the fossils in *Der Jura* are excellent, and the keen and accurate observation even of the most concealed features calls forth the highest admiration. The work found

a wide circulation among non-professional classes, and created a popular interest in fossil remains. Numerous collectors and dilettantes read their "Quenstedt" over and over again, and tried to apply the same methods of arrangement to their particular collections. And the farmers of the neighbourhood were so well trained by Quenstedt not to overlook any of the fossil riches that might happen to be exposed in the course of field-cultivation, they became quite proficient in identifying the fossils and in recognising the individual zones by Quenstedt's designations.

Quenstedt gave little heed to the rights of priority, and on account of his neglect of the formal rules in palæontological science came into conflict with D'Orbigny. Neither did Quenstedt care to institute a close parallelism between the English and French Jurassic formations and those in Würtemberg; he merely indicated the correspondence of the main sub-divisions in Würtemberg with similar groups in the adjacent areas, and on principle refused to use the English terminology for the sequence of zones which he had established for the Swabian Jurassic system.

A much broader standpoint of palæontological investigation was assumed by the far-travelled Alcide d'Orbigny.[1] His great desire was to establish a universal stratigraphy upon the chronological basis supplied by palæontology. Not only in all parts of France, but also in the other countries of Europe and in North and South America, D'Orbigny thought the same sequence of fossil remains could be identified, and he argued that the age limits of the formations (Terrains) and stages of deposit could be determined over the whole surface of the earth by the universal occurrence of the same leading palæontological features.

According to D'Orbigny, each stage of deposit possesses its

[1] Alcide Dessaline d'Orbigny, born on the 6th September 1802, at Couëzon (Loire Inférieure), received his early education in La Rochelle, and devoted himself very early to zoological and palæontological studies. In 1826 he was sent to South America by the Museum in Paris, and brought back with him splendid collections of zoological, geological, geographical, ethnographical, historical, and archæological interest. The results of this journey were afterwards published in a comprehensive work. His later works deal with palæontological and stratigraphical subjects. In 1853 D'Orbigny was appointed Professor of Palæontology at the Museum in Paris, the Professorship being established especially for him; died on the 30th June 1857, at Pierresitte near Saint Denis.

independent fauna, which owes its origin to a special act of creation, and is clearly distinguishable from the preceding and succeeding faunas. It happens in rare cases that species are continued into a higher complex of strata than that in which they took origin, but these cases occur only when the higher strata succeed conformably upon the lower, in other words, when no marked crust-disturbance has taken place between the two periods of deposition. Thus D'Orbigny thought it possible to base stratigraphy wholly upon palæontological features, more especially upon the occurrence of Mollusca, Echinodermata, and Cœlenterata.

He commenced a great palæontological work, which was intended to supply a description of all the fossil forms in France belonging to these three divisions of the animal kingdom. The gigantic scope of the work was too much even for such an enthusiastic worker as D'Orbigny. Between 1840-55 several volumes of D'Orbigny's *Paléontologie Française* appeared, comprising descriptions of the Jurassic and Cretaceous Cephalopods, part of the Gastropods from the same two systems, and the Cretaceous Brachiopods and Hippurites, Irregular Echinids, and Bryozoa. In two other works, the *Elementary Course of Palæontology* (1849-52) and the *Prodrome of Stratigraphical Palæontology* (1850-52), D'Orbigny elucidated his sub-division of stratified rocks and his views on stratigraphical geology.

He divided fossiliferous rocks into six periods or Terrains, and sub-divided the first five periods into twenty-seven groups (étages). He selected the names of characteristic localities for the designation of the groups of strata, and followed Thurmann's example in adding the affix "ien" to give uniformity to the series. D'Orbigny was thoroughly familiar with the Mesozoic faunas but knew less about those of other epochs, and he made the mistake of assigning to the Mesozoic faunas a much greater significance in his stratigraphical succession than to the Palæozoic or Cainozoic faunas. He discarded the terms Palæozoic, Mesozoic, and Cainozoic, and assumed an equal value for the twenty-seven successive groups which he distinguished. In accordance with his sub-division of the rock-succession, D'Orbigny supposed that organic creation had been completely renewed twenty-seven or twenty-eight times.

The chief merit of D'Orbigny's works is their remarkable

precision and lucidity of statement, which opened their contents to geologists of all nationalities, and enabled them to exert a great influence upon literature. His *Paléontologie Française* is a work of the first rank, and after D'Orbigny's death the French Geological Society resolved to continue it. Cotteau, Deslongchamps, Piette, De Loriol, and Fromentel added special portions, but finally the scheme had to be given up for lack both of the means and of scientific workers.

D'Archiac, who succeeded D'Orbigny as Professor of Palæontology in Paris, was thoroughly versed in the geology of the French Jurassic deposits, and in the sixth and seventh volumes of his history of the progress of geology he gave an exhaustive criticism of all the publications on these deposits which had appeared before the year 1856. D'Archiac takes the English development of Jurassic rocks as the basis of comparison, and tries to bring the observations in all other parts of the world into harmony with the main sub-divisions established in the English series. At the same time, he agrees with Dufrenoy, Élie de Beaumont, and D'Orbigny in assuming it to be quite impracticable to carry out any comparison of detailed zonal sequences in distant localities.

As Quenstedt had not attempted to compare the Swabian development of Jurassic rocks with the succession in other countries, some of his students made a special study of the comparative stratigraphy and palæontology. O. Fraas travelled through France and England, and afterwards contributed a memoir to the *Neues Jahrbuch* in 1850. He established the parallelism of many of the zones by means of fossil identifications, and at the same time gave a careful account of the differences of the local facies, and supported Gressly and Quenstedt in their view that the local English names should not be applied to other areas. While Fraas succeeded in demonstrating that the Lias and "brown Jura" of Würtemberg were represented by synchronous formations in France, England, and Switzerland, he experienced great difficulty in finding an exact equivalent for the "white Jura" of Würtemberg.

What Fraas had only indicated in broad features, Albert Oppel,[1] another student of Quenstedt's, worked out in detail.

[1] Albert Oppel, born 1831 at Hohenheim, studied at the Polytechnic School in Stuttgart and under Quenstedt in Tübingen; in 1854 and 1855 travelled through France, England, Switzerland, and Germany, in order to

In the course of a local study on the Middle Lias in Swabia, he proved himself to be an excellent observer and able palæontologist. He then visited the famous "Jurassic" localities in France and England, and endeavoured to compare not only the main sub-divisions, but also the smallest groups of strata in the different areas by means of the fossil species occurring in them. Setting aside all lithological features, Oppel deduced from his observations a series of palæontological horizons which he termed *Zones*, each of which represented the definite age-limit of some leading fossil type or types. "*A Zone*," he says, "*is characterised as a definite palæontological horizon by the constant occurrence in it of certain species which do not occur in the preceding or succeeding neighbour zones.*"

Oppel accepted Buch's division of the Jurassic system in three main groups as the foundation of his own detailed subdivision. He retained the English term *Lias* for the lowest division, proposed the name *Dogger* for the middle division, and *Malm* for the upper division. These names had already been used in England for rocks of different age; and D'Omalius Halloy had applied *Malm* to a division of the Cretaceous formation. The three main groups were sub-divided by Oppel in eight zones, which agree in the essential features with those suggested by D'Orbigny, and for which he retained D'Orbigny's nomenclature. He, however, modified D'Orbigny's zones in so far as to omit the "Corallien" and "Portlandien," on the ground that they were local facies of the "Oxfordien" and 'Kimmeridgien." Oppel's sub-division of the whole Jurassic system embraces thirty-three zones, each of which is characterised by a particular fossil type.

Oppel's admirable work, published in 1856-58, was received very favourably throughout Germany, France, and England, the cordiality of the reception being not a little increased owing to the general regard in which the author was held. In France, D'Archiac took objection to certain points, but Jules Marcou, always ready for a scientific debate, lent ardent support to Oppel, and the controversy soon collapsed. Marcou had previously published a local monograph on the Jura near Salins (1848). In it he had accepted the divisions

compare the Jurassic deposits with one another; in 1858 was attached to the staff of the Palæontological Museum in Munich, in 1860 was appointed Professor of Palæontology, and in 1861 Director of the Palæontological Collection in Munich; died in 1865 from typhoid fever.

of Thirria and Thurmann for the most part, but had also introduced several new names. Marcou had distinguished twenty-six sub-groups which very nearly correspond with Oppel's zones, but he had named his sub-groups not according to leading fossils, but from the names of the localities where they were well developed. It was not altogether surprising then that Marcou should raise some doubts regarding the nomenclature proposed by Oppel. The letters which he wrote upon this subject are of interest for their clear representation of the state of Jurassic research at the time, and for many new ideas about the distribution of the Jurassic fossils. Marcou referred to the valuable researches by Edward Forbes, elucidating the differences of marine faunas in the present time, the confinement of certain faunas within definite geographical limits, and the occurrence of particular types at definite ocean-depths. Applying Forbes's principles of biological provinces and bathymetrical horizons to the elucidation of the Jurassic faunas, Marcou drew maps showing the probable distribution of land and water in the successive Jurassic eras, and trying to determine the chief biological provinces in the Jurassic Ocean. He distinguished eight Jurassic provinces, and correlated their geographical position with three "homozoic" climatic zones which had exerted an influence on the distribution of the organisms.

The work of Oppel has undoubtedly exerted a marked influence upon subsequent stratigraphical research. Although many geologists could not feel convinced of the universal application of a sequence of palæontological zones, the exact method pursued by Oppel gave an excellent precedent, and the study of the local developments of Jurassic deposits was renewed with fresh vigour. A student of Oppel's, W. Waagen, endeavoured to identify the same zones in Franconia and Switzerland; the name "Jurassic System" was generally adopted after the publication of Oppel's work, and numerous memoirs appeared wherein the older groups were subjected to more detailed examination. Buckman thought it possible to sub-divide the English series into even more limited horizons than were represented by Oppel's zones, and sub-divided the latter into "Hemeræ," each of which was characterised by a typical Ammonite species.

The Jurassic deposits of the Alps, the Pyrenees, the Apennines, the Carpathians, the Balkan mountains, the Iberian

Peninsula, and Russia, were comparatively late in being examined and surveyed, and it seemed scarcely possible to determine the parallelism of the facies in these areas with the Jurassic deposits of North-Western and Central Europe. In the Swiss Alps, geologists have identified the age of the larger Jurassic groups, but have not attempted a detailed comparison with the extra-Alpine zones. In the Bavarian, Austrian, and Italian Alps, as well as in the Apennines and the Carpathians, the Alpine facies is also fundamentally different from the extra-Alpine, but it has been possible to identify locally some of Oppel's zones. Alpine geologists invariably try to recognise in the Alpine Trias the equivalents of Oppel's chief groups, *Lias*, *Dogger*, and *Malm*.

No serious attempt has ever been made to apply Oppel's zonal nomenclature in Alpine geology. It has been customary, especially in Austria, to designate the various sub-divisions with the names of localities (Adneth limestone, Gresten, Hierlatz, Allgäu, Vils, Stramberg strata, etc.).

After the controversy regarding the proper systematic position of the Avicula contorta zone or Rhætic group had been brought to a fairly satisfactory conclusion (p. 479), considerable discussion began to be raised about the proper limit between the Jurassic and the Cretaceous formations. In France, South Germany, and in the Swiss Jura there was no difficulty, as the uppermost numbers of the Jurassic system (Portland and Purbeck strata) are well defined both petrographically and palæontologically, and the limit between these horizons and the Cretaceous formations can be readily determined. On the other hand, in the south of England, North Germany, and Belgium, a fresh-water formation (Weald clay and Hastings sand) is interposed between the uppermost Jurassic and the Cretaceous horizons, and creates a difficulty in determining the precise limit of the two formations. Mantell united the fresh-water formation with the Cretaceous Greensand; Webster and Fitton combined them with the Purbeck strata, and regarded the group as independent. Sir Richard Owen and Robertson drew attention to the similarity of the Purbeck and Wealden faunas with that of the Stonesfield slate, and placed the Wealden in the Upper Jurassic division. Élie de Beaumont supported the other view, that the Wealden formation was an equivalent of the "Néocomien," and Forbes, Lyell, Topley, the Geological Survey, and most of

the English geologists assigned the Wealden formation, exclusive of the Purbeck strata, to the Lower Cretaceous horizon.

The definition of a limit has proved even more difficult in the regions with Alpine facies, where there is no littoral series of passage-beds from Jurassic to Cretaceous horizons. Marine strata of Upper Jurassic age are frequently covered conformably by similar deposits of Lower Cretaceous age, and any line of separation seems at first sight necessarily of an arbitrary character. Oppel, in a contribution to the *Zeitschrift* in 1865, opened the question of the Jurassic-Cretaceous limit in the Alps. He comprised under the name of "Tithonian Horizon" a number of Alpine and Carpathian deposits (the *Diphya limestones* of South Tyrol, the Northern Alps and Dauphiné, the *Aptychus shales*, the *upper mountain limestone* of the Northern Alps, and the *Stramberg strata*), together with the lithographic shales of Bavaria and Nusplingen, the Purbeck and Portland strata of England and the North of France, and on the basis of their peculiar Cephalopod fauna classified the Tithonian series as an independent group of strata between the Kimmeridge and the Neocomian horizons. Regarding the precise systematic position, Oppel seemed to incline rather to the inclusion of the Tithonian group in the Jurassic system. An enumeration of one hundred and seventeen Cephalopod species, most of them from Stramberg, Rogoznik, South Tyrol, and the lithographic shales of Franconia, affords the evidence upon which Oppel erected the Tithonian horizon.

Long before Oppel's paper, Beyrich had in 1844 drawn attention to the relations of the "Klippen limestone" and "Stramberg limestone"; and Stur, Hauer, Hohenegger, and Suess (1858) had identified both these limestone formations as Upper Jurassic, whereas Zeuschner (1844-48) had assigned the "Klippen" limestones of the Carpathians at first to Upper Jurassic, then to Neocomian, and had stated that the fauna was a mixed Jurassic and Cretaceous fauna.

Benecke showed, in his able work on the Triassic and Jurassic deposits of the Southern Alps (1866), that two faunas are contained in the red Jurassic Ammonite limestone, the younger of which contains *Terebutula diphya* as the leading fossil, and a number of peculiar Ammonites. The older is characterised by *Ammonites acanthicus* and other Upper Jurassic Ammonites. Benecke paralleled both horizons with

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the Kimmeridge group. Similar results were afterwards obtained by Stache, Mojsisovics, and Neumayr in an examination of the "Klippen" limestones in the Carpathians. These geologists placed the *Ammonite acanthicus* strata with the Upper Jurassic, the *Diphya* limestones with Oppel's Tithonian horizon.

The premature death of Oppel prevented the completion of the series of investigations by means of which he had intended to establish the Tithonian horizon on a secure palæontological basis. The material was afterwards examined and described in a series of special monographs by Zittel, Böhm, Cotteau, Miss Ogilvie, and Zeise. Zittel limited the term "Tithonian" to formations of Alpine facies, excluding therefore the lithographic shale and Portland limestone, and he regarded the Tithonian complex of strata as the equivalent of the Purbeck and Wealden strata.

Whereas Oppel, Zittel, and Benecke expressed themselves more in favour of the Jurassic age of the Tithonian horizon, Hébert attributed great weight to its affinities with the lowest Cretaceous deposits in the south of France (Berrias strata), and even went so far as to place the Stramberg strata in the Lower Cretaceous. Many eminent geologists have taken part in the discussion within recent years, and the opinion now most generally held is that the lower portion of the Tithonian group is the equivalent of the Upper Kimmeridge horizon, while the higher portion of the Tithonian group is parallel with the Purbeck and Portland strata.

New discoveries by the Russian geologists have lately enriched the knowledge of Upper Jurassic faunas. In Central Russia, marine deposits of Lower Cretaceous age succeed dark argillaceous strata which represent the whole Upper Jurassic series from the Kellaways zone upward. The fossils of the Moscow and South Russian Jurassic deposits are now being carefully examined by Trautschold, Pavlow, Sinzow, Lahusen, and Nikitin, and the so-called Volga group has been identified as an equivalent of the Tithonian Alpine formations. Oppel's students, Neumayr and Waagen, tried to develop the zonal aspect of geology more and more, and to apply it in foreign parts of the world. Waagen's attempt to demonstrate almost all the Upper Jurassic zones of Oppel in the Jurassic strata of Cutch has been contested by Kitchin and Nötling.

Neumayr advanced the palæontological knowledge of

the Jurassic Cephalopods in several excellent monographs. He also followed Marcou's method of discovering the biological provinces of the Jurassic epoch. In Europe three provinces were distinguished by Neumayr—a Mediterranean (Alpine), a Central European, and a Russian or boreal province. These were supposed by Neumayr to correspond to three climatic zones which entirely girded the earth's surface, and were probably repeated in the southern hemisphere. In evidence of this theory Neumayr cited the fact that the Jurassic fossils from South America, New Zealand, South Australia, and South Africa strongly resemble those of the corresponding deposits in Swabia, France, and England, but differ completely from the Alpine type. Neumayr (1885) likewise gave sketch-maps of the Jurassic seas and continents, and pointed out the far wider distribution of the Upper Jurassic deposits than of the Liassic. From this he concluded that there had been an extensive Liassic continent which gradually became submerged by the advance of the Jurassic ocean.

According to the more recent investigations of Pompeckj (1897), however, the assumed non-occurrence of the Lias in the south-east of Europe, in Asia Minor, and Persia is rather due to the scanty information regarding the geological constitution of those lands than to an actual absence of the Liassic deposits in those lands; in his opinion, the significance of the Jurassic transgression has been over-estimated.

H. *Cretaceous System.*—The deposits which are now comprised under the name of the Cretaceous system were first studied in the Anglo-Parisian basin. But the examination of the rocks in this area provided no general systematic type, according to which the contemporaneous developments in other areas could readily be arranged. The remarkable differences in the local lithological and palæontological facies made it extremely difficult to recognise the contemporaneity of Cretaceous sediments, even in areas at no great distance from one another. Hence the geological knowledge of this system advanced slowly and in a fragmentary way. The sequence of rocks and organic types had to be independently elucidated in each locality. And it has been found impossible to determine any constant succession of faunal zones applicable over larger tracts of country, such as geologists have established for the

Jurassic rocks in Central and North-Western Europe, and in Great Britain.

In Germany, Charpentier in 1778 distinguished *Pläner* limestone and *Quader* sandstone in his geological map of Saxony. Werner and his pupils placed these formations amongst the younger "Flotz" series. William Smith had recognised in England four strata between the London clay and the Portland stone:

4. White Chalk.
3. Lower or Grey Chalk.
2. Greensand.
1. Micaceous Clay (Brick earth).

In Cambridgeshire, dark plastic clays occur below the Greensand, and Michell had in 1788 designated these as *Gault* or *Galt;* W. Smith called them *Blue Marl.* Conybeare and Phillips sub-divided the series into two groups:

2. The Chalk.

1. (*d.*) Chalk Marl.
   (*c.*) Greensand.
   (*b.*) Weald Clay.
   (*a.*) Ferruginous Sand.

The White Chalk was early described, and the similarity of its lithological and palæontological features established in the south-east of England, the north of France, Belgium, Denmark, Sweden, North Germany, and Poland. D'Omalius d'Halloy traced the formations of the Paris basin into Belgium, distinguished four groups of deposit in ascending order, (*a*) grey clay, (*b*) sand and sandstone (Tourtia), (*c*) chalk marl, (*d*) chalk and flint, and comprised these in one formation, which he named "Terrain crétacé." In the same year, 1822, Brongniart and Cuvier published a detailed description of the deposits of the Paris basin in the second edition of their work, *Récherches sur les ossements fossiles.* After a careful comparison of the French Cretaceous formations with the English, Belgian, and Scandinavian, Brongniart added a description of the chloritic Cretaceous deposits of the Savoy and of the Perte du Rhône, near Bellegarde, together with an enumeration of the fossils occurring in them.

Another work of that year which considerably advanced the knowledge of Cretaceous rocks was that of Gideon Mantell on

The Fossils of the South Downs, or Illustrations of the Geology of Sussex. Like Conybeare, he distinguished two formations, Greensand and Chalk, each of which was divided into sub-groups. The Blue Marl (Gault or Malm) in Mantell's system forms the lowest horizon of the Chalk deposits, and is said to be superposed upon the Greensand formation; in the latter Mantell includes the various horizons of the true Greensand, the Wealden or Oak-tree Clays, the Tilgate beds, and the ferruginous sand. An atlas, with forty-two plates, contains a geological map of Eastern Sussex and several geological sections, also sketches of characteristic landscapes in the Cretaceous area and illustrations of the fossils belonging to the successive horizons. The best portion of the work is Mantell's description of the three lower horizons of the Greensand formation, which had been in 1828 designated as "Wealden formation" by Martin and Fitton. Mantell afterwards discovered skeletal remains of Iguanodon, Hylæosaurus, and other reptiles in the Tilgate strata, and otherwise contributed very greatly to our knowledge of the fauna and flora of the fluviatile Wealden formation.

In Yorkshire the lower greensand, and perhaps also the Wealden horizon, is replaced by clays and oolitic ironstones, to which J. Phillips gave the name of *Speeton Clay.* The parallelism of the argillaceous and ferruginous series of Yorkshire with a similar marine facies of Neocomian deposits in Russia, has recently been made the subject of combined investigations by Lamplugh and Pavlow.

W. H. Fitton was the first to arrive at definite results regarding the stratigraphy of the older Cretaceous deposits in England. His paper, entitled "Observations on some of the Strata between the Chalk and the Oxford Clay," was read at the Geological Society in 1827, but not published until 1836 in the *Transactions.* In it Fitton retained both sub-divisions, Chalk and Greensand, but assigned the *Upper Greensand* layers of Blackdorn, etc., to their correct stratigraphical position, and recognised the *Lower Greensand* as the basement beds below the *Gault.* Numerous sections, a geological map, and lists of fossils accompany the accurate and fundamental observations of this geologist. A combined work, published by Buckland and De la Beche in 1830, contains valuable information regarding the stratigraphy of the Cretaceous formation in Dorsetshire.

The Quader Sandstone and Greensand in North Germany were united with the White Chalk by Hoffmann in 1830, and recognised as the equivalents of the Cretaceous system. He compared the *Quader Sandstone* with the upper and lower greensand deposits; the *marly, calcareous, or siliceous rocks* between Quader Sandstone and Chalk in North Germany with the Chalk Marl of the North-Western basin; *the grey, earthy marls and white chalk* with the Lower and Upper Chalk of England.

The discovery of older Cretaceous deposits in the Swiss Jura mountains was an important step in advance. As far back as 1803, Leopold von Buch had drawn up a very detailed catalogue of the rocks in the neighbourhood of Neuchâtel, but his manuscript was not published until sixty-four years later, after the death of the author. A copy of the manuscript had been, however, presented by Ami Boué to the library of the French Geological Society, and geologists had tried in vain to find equivalents for the series of strata described in it.

In 1836 Auguste de Montmollin demonstrated that the youngest Jurassic rocks were succeeded by a diversified complex of strata comprising yellowish limestone and blue marls, whose fossils resembled those of the English greensand; Montmollin called the complex "Terrain crétacé du Jura," and Thirria, who almost simultaneously found similar strata in the neighbourhood of Besançon, applied the name of "Terrain Jura-Crétacé."

But before the actual publication of Montmollin's treatise, Thurmann had made the proposal at a Congress of the French Geological Society in Besançon (1835) to introduce the designation of *Néocomien* for the newly-discovered complex of strata, and this name was immediately adopted by Dufrenoy and Élie de Beaumont, and received the authority of their geological map and text. These two authors sub-divided the Cretaceous formation into a *Lower Group*, comprising (*a*) Wealden, Neocomian, and ferruginous sand; (*b*) Greensand; (*c*) Chalk Marl; and an *Upper Group* represented by the White Chalk. The chief divisions of the Cretaceous deposits having been thus definitely fixed in France, the following years between 1835 and 1860 were signalised by the publication of an extraordinary number of special papers devoted to the geology and palæontology of the Cretaceous system in French localities.

Two valuable memoirs were published in 1841 and 1842 on

the lower Cretaceous formations of the south-eastern part of the Paris basin. Cornuel described deposits in the Haute-Marne which he identified partly as Gault (Marnes à Plicatules), partly as lower Greensand, partly as Neocomian. The localities Bassy and St. Dizier have been regarded since that time as types of the lower Cretaceous development in the north-east of France.

Leymerie's memoir on the Cretaceous deposits of the Aube Department was published by the French Geological Society in 1841. It still ranks as a classic in the geological literature of the Paris basin. Leymerie distinguished three sub-divisions in the Cretaceous system: Neocomian, Greensand and Brick-clays, White Chalk. Each horizon was accurately described, and the distribution of the fossils was indicated with scrupulous care and detail. According to Leymerie, the horizon of the *White Chalk* contains the same organic remains as the Upper and Lower Chalk and the Chalk Marl of England. The *Brick-clays* (Argile téguline) and *Greensand* group comprises two sub-groups, the younger of which corresponds to the Gault, the older contains fossils which are known to occur in the Upper and Lower Greensand as well as in the Gault of the English area; this is the group which D'Orbigny afterwards called *Aptien.*

The Neocomian reposes upon the Upper Jurassic rocks, and consists of three sub-groups: Marls with variegated sandy deposits; Marls and limestones with *Exogyra subplicata, harpa,* etc.; Spatangus limestone (the name being given on account of the abundant occurrence of tests of *Echinospatangus cordiformis*). An accurate comparison of the Neocomian in the north of France with the Lower Cretaceous formations of England led Leymerie to the conclusion that the French Neocomian was *not* the equivalent of the Lower Greensand of England, but, as had already been said by D'Archiac, it represented the Wealden formation of England. The palæontological part of Leymerie's work appeared in 1843, and included a description of one hundred and thirteen new species from the Neocomian horizon.

In 1842, a mineralogical and geological description and a geological map of the Ardennes Department was published by C. Sauvage and A. Buvignier. The two authors demonstrated that the Cretaceous system was here represented by the White Chalk, the Greensand or the Chalk Marl (Gaize), highly

fossiliferous Gault and unfossiliferous Lower Greensand. D'Archiac's admirable work, *Description géologique du Département de l'Aisne*, provided supplementary information about the Cretaceous deposits in this part of France. The Upper or White Chalk and the Greensand formations were shown to be well developed, the lower horizons of the Cretaceous to be absent.

No less important was another work by the same author on the middle group of the Cretaceous system (1839). D'Archiac gave in this work a lucid exposition not only of the Middle division but also of the whole Cretaceous series in the marginal areas of the Paris basin, in Belgium, and the neighbourhood of Aix. He compared the sequence of deposits with the succession in England, Switzerland, and Germany, and finally sub-divided the system as follows:—

Upper Group.	Upper horizons of Chalk (Maestricht, Sweden).	
	White Chalk.	
	Chalk Marl.	
Middle Group.	Upper Greensand.	
	Blue Marl (Gault).	
	Lower Greensand.	
Lower Group.	Neocomian (Marine facies).	
	Wealden (Fresh-water facies).	Weald clay.
		Hastings sand.
		Purbeck strata.

While the greatest enthusiasm prevailed among French geologists to elucidate the Cretaceous system, Germany had fallen rather behind in this work. Friedrich Roemer and Hans Geinitz were the leading contributors to the knowledge of the German Cretaceous deposits. In 1836, Roemer had described a marine deposit in the Hils basin under the name of "Hils Clay," but had relegated the Hils clay, along with the Wealden formation, to the Upper Jurassic horizon. In 1839, however, he demonstrated that the Hils clay was younger than the Wealden formation, and possibly represented the Speeton clay of England. The careful investigation of the fossils in the Hils clay showed, according to Roemer, distinct affinities both to Upper Jurassic and Cretaceous faunas. Two years later Roemer published his important monograph of the *Fossils*

of the North German Cretaceous Rocks, accompanied by a short geological description of the succession. In this work Roemer referred the Hils conglomerates of Osterwald, Berklingen, and other localities, together with the Hils clay of the Deister and the Hils basin, to the lowest Cretaceous horizon. Their fossil contents led him to regard these German deposits as the equivalents of the *Neocomian* strata in the Paris basin, at Neuchâtel, and in the south of Russia. The higher deposits were thus sub-divided by Roemer:—

Upper Cretaceous.	*The White Chalk*, Maestricht limestone, and *Uppe Chalk Marls;* also the *Quader Sandstone* of Quedlinburg and Blankenburg, the *Glauconite Marls* of Kieslingswald, and the Marls at Luisberg, near Aix.
Lower Cretaceous.	7. *Lower Chalk without flints* at Lüneburg, Lindener Berg, etc. 6. *Lower Chalk Marls* at Ahlten, Lemförde, etc., the sandstones with fish remains, the marls of Ilseburg, and the sponge strata near Goslar. 5. *Pläner Limestone* of Essen, Quedlinburg, etc. 4. *Greensand* of Oberau and the mottled marls with *Avicula gryphæoides* in Hanover and Brunswick. 3. *Gault* of Goslar and Sarstedt. 2. *Lower Quader Sandstone* of the Harz mountains, in Brunswick, and in the Hils basin; in Teutoburg forest, Saxony, Bohemia, and Silesia. 1. *Hils Conglomerate and Clays.*

Although Roemer's sub-division of the German development is in many respects deficient, it was the first noteworthy attempt at a recognition of the distinctive facies in this area and a comparison with the English, French, and Swiss developments.

Charpentier had in the eighteenth century contributed a geological sketch-map of the surface outcrop of Quader Sandstone in Saxony. Naumann and Cotta in 1835 demon-

strated that calcareous and marly strata (Plänerkalke) are present between the Upper and Lower Quader Sandstone, and contain in some localities a rich marine fauna. Cotta thought these marine limestones were the time-equivalents of the Gault clays. Geinitz published, between the years 1839-42, an excellent *Monograph on the Strata and the Fossils of the Cretaceous Rocks in Saxony and Bohemia.* His results confirmed Cotta's surmise, and upon palæontological evidence established the equivalents of the German and British developments: —

4.	Upper Quader Sandstone . .	= White Chalk.
3.	Upper Pläner Marls	= Lower Chalk. Chalk Marl.
2.	Middle and Lower Pläner Limestone and Marls . . .	= Upper Greensand Gault.
1.	Lower Quader Sandstone . .	= Lower Greensand.

August Emmanuel Reuss, the famous Austrian authority on the Cretaceous system, published in 1843 and 1844 the first results of his detailed researches on the Cretaceous deposits of Bohemia. Two years later, his monograph on the Bohemian Cretaceous formations appeared, and this work has been regarded as the fundamental stratigraphical work on the Bohemian facies. The four chief divisions distinguished by Reuss are: 1, The Lower Quader Sandstone, present in Bohemia in its full development; 2, the Pläner marls, richly fossiliferous; 3, the Pläner limestones, together with the conglomerates reposing upon them; 4, the Upper Quader Sandstone, poorly fossiliferous, but attaining very great thicknesses in Bohemia.

The insecurity of the systematic position of the Lower and Upper Greensand in England induced Fitton to undertake a renewed examination of those deposits in the Isle of Wight. The result, published in 1847, showed conclusively that the Lower Greensand was an equivalent of the Neocomian.

A very great influence was exerted upon the systematic arrangement of the Cretaceous system by the publication of D'Orbigny's *Paléontologie Française.* In the second volume of this gigantic work, D'Orbigny introduced a new classification of the Cretaceous formations, which was based upon intimate knowledge of the French development. He divided the system into five stages, named in accordance with typical

localities, in ascending order, Néocomien, Aptien, Albien (Gault), Turonien, Senonien. In D'Orbigny's *Elementary Course* and his *Prodrome*, he inserted two additional stages: Urgonien, between Neocomien and Aptien; and Cenomanien, as the equivalent of the Upper Greensand between Albien and Turonien.

The horizons defined by D'Orbigny were soon generally accepted in France, in spite of some resistance shown by D'Archiac. They were also gradually adopted in other European countries, with the exception of Great Britain, where geologists still continued to use the classificatory horizons and terminology introduced by W. Smith, Conybeare and Phillips, and Fitton.

In the year 1876, Barrois made a very successful effort to identify in the Upper Cretaceous deposits of England and Ireland the same zonal sequence as had been established by Hébert for those deposits in the Paris basin. The systematic arrangement drawn up by Barrois found recognition in England, and the comparison was carried out by Horace Woodward in his *Geology of England and Wales* (1887) for the complete series of Cretaceous deposits. It seems, therefore, at the present day, as if the stratigraphical succession of the youngest Mesozoic system had been fairly well worked out in England and the Paris basin.

In Germany also, the comparative aspect of the groups and zones in the different areas has become much better known. In 1849, Geinitz published a general survey of the Cretaceous formation in Germany, tracing the four main sub-divisions which he had previously recognised in Saxony and Bohemia in their further extension towards the Baltic, the Rhine, Poland, and Hungary. In the course of his researches, he corrected several blunders that had been made by previous authors; for example, he identified the true age of the greensand at Essen, and the Pläner marls at Priesen in Bohemia; and Geinitz also compared all the horizons of the German Cretaceous deposits with the "Stages" established by D'Orbigny for the French development.

Beyrich's study of the Cretaceous system in Silesia and the northern skirt of the Harz mountains elucidated the stratigraphical and tectonical relations of that region in a masterly way. Beyrich's memoir was published in the *Zeitschrift* in *1849*, and in this and several later contributions, Beyrich

expressed his disapproval of the term "Quader-Sandstone Formation," which Hoffmann had suggested for the Cretaceous system in Germany, and Geinitz had supported and adopted. Beyrich and his friend and colleague, Julius Ewald, held strongly to the uniform acceptance of D'Orbigny's classification.

An interesting treatise was written by Leopold von Buch in 1849 on the geographical distribution of the Cretaceous formations. Buch tried to show that unlike the Jurassic and Triassic rocks, the Cretaceous rocks nowhere extended into the higher polar regions in Europe, Asia, and North America, but were chiefly confined to the temperate zones. He concluded from this, that the influence of the earth's internal heat had diminished in the higher latitudes, and that the geographical limits of the Cretaceous formations gave an indication of the surface distribution of the earth's internal heat.

Geinitz and Beyrich had pointed out the general agreement between the Cretaceous formations in the neighbourhood of Regensburg and Kelheim and those in Bohemia and Saxony. Gümbel, as director of the Bavarian Survey, was in a position to bring out in full detail the equivalence of the Bavarian deposits with those of the adjacent countries. This he accomplished in an admirable work published by the Bavarian Academy in 1868. The Bavarian deposits have yielded very valuable and plentiful fossil remains.

As has appeared from the context, D'Archiac rejected D'Orbigny's arrangement and nomenclature of the French Cretaceous deposits. His *Histoire des Progrès de la Géologie* (1853) still retained the older classifications. On the other hand, the most distinguished representative of the stratigraphical direction of research, Hébert,[1] adopted D'Orbigny's sub-divisions, and won for them a secure foundation in virtue of his detailed and excellent investigation of the Cretaceous formations of the Paris basin, Belgium, the neighbourhood of

[1] Edmond Hébert, born 12th June 1812, at Villefargeau (Yonne), son of a large agriculturist, studied in Auxerre and Paris at the Normal School; in 1836 became professor at Meaux; returned in 1838 as demonstrator in Chemistry and Physics at the Normal School in Paris; and was in 1852 appointed Master of Conferences for Geology. In 1857 he succeeded his teacher, Constant Prévost, as Professor of Geology at the Sorbonne, and displayed remarkable activity as a teacher there until his death on the 4th April 1890.

Rouen, and Le Mans (1847-58). His support of D'Orbigny's groups brought Hébert into conflict with his rival, the gifted but rather fiery native of Provence, Henri Coquand.

The south and south-west of France had been Coquand's field of research, Hébert's work had lain in the north of France, and the facies variations of the rocks were undoubtedly chiefly answerable for the want of harmony in the results obtained by the two field geologists. Coquand was engaged for eight years on a survey of the Charente, but his results, published 1858-60, would neither agree with D'Archiac's nor with D'Orbigny's systematic sub-division of the Cretaceous system. Coquand found that the Cretaceous deposits in the south began with the Upper Cenomanian, and that the most natural sub-division would be into eight groups, which were mainly characterised by the abundance of species of the Hippuritid family, whereas in the north of France there were scarcely any Hippuritids.

Coquand erected a number of palæontological zones for the Cretaceous development in the Charente, and traced the continuation of these into Provence and Algeria. To the Cenomanian and Turonian, Coquand ascribed the stages *Rhotomagien*, *Gardonien*, *Carentonien* (zone of *Exogyra columba*), *Angoumien*, and *Provençien;* to the Senonian and Danian he ascribed the stages *Coniacien*, *Santonien*, *Campanien*, and *Dordonien.* In 1862 he added a new stage, *Mornasien*, between the Carentonien and Angoumien for the sandstones of Uchaux and Mornas; and in 1869 he inserted a new stage, *Ligérien*, between the Carentonien and Mornasien. Coquand also added the stage *Barrêmien* to the lower Cretaceous between Neocomien and Urgonien for Cephalopod-bearing strata at Barrême and other localities in the Basses Alpes which D'Orbigny had regarded as a facies of the Urgonien.

Coquand's special nomenclature for the southern Cretaceous development was willingly accepted by the geologists in the south of France, but was strongly contested by Hébert. The Parisian stratigrapher also doubted the presence of true equivalents of the White Chalk with Belemnitellas in the areas of Touraine, Charente, Dordogne, and Provence; in his opinion, Coquand had erroneously compared the Dordonien and Campanien with the Senonien and Danien of the north; Hébert thought they represented only the lower Senonien.

At the present day the general tendency in France is to

adhere firmly to D'Orbigny's sub-division and nomenclature, and where necessary to form sub-groups and sub-stages. Thus Renevier gave to the passage-beds between Urgonien and Aptien at the Perte du Rhone, the distinctive name of *Rhodanien*, and the name of Vraconien to the uppermost horizons of the Gault in the Jura of the Waadt Lands. Again, Pictet separated certain basement beds of the Neocomian in the French Rhone Valley as a sub-stage, *Berriasien*, characterised by special fossils also widely distributed in the Alps and Carpathians and in Algeria.

The Cretaceous deposits play a relatively subordinate part in the Swiss and Eastern Alps and in the Carpathians, and could not be properly understood until the stratigraphy of extra-Alpine Cretaceous formations had been elucidated. In Switzerland, Studer had as early as 1836 demonstrated the presence of Lower Cretaceous deposits near Interlaaken, and afterwards Studer and Escher von der Linth together studied the Cretaceous rocks at Lake Lucerne, the Glärnisch and Sentis mountains. Renevier, Favre, and Schardt have chiefly contributed to the knowledge of the interesting Cretaceous sequence in the Waadt Lands and Savoy Alps.

The Vorarlberg Cretaceous deposits were examined by Von Richthofen, Gümbel, and Vacek, those of the Bavarian Alps by Gümbel. In the Austrian Alps the "Gosau Strata" have yielded a remarkable profusion of well-preserved fossils. In 1822, Ami Boué observed these fossils on the cliffs near Wiener Neustadt; he thought at first that they were Jurassic, but afterwards included them in the Greensand formation. Keferstein united them (1827) with the Tertiary "Flysch," although Count Münster had identified Cretaceous species amongst the fossils. Murchison likewise placed the Gosau marls in the Tertiary epoch, but ascribed a greater age to the Hippurite or Rudistes limestone with which they are associated.

The Austrian geologists wavered between Gault and Upper Cretaceous as the systematic position of the Gosau marls, until in 1852, just thirty years after their first discovery, Zekeli concluded from his investigation of the Gosau gastropods, that the strata containing them must be the equivalent of D'Orbigny's Turonien and Senonien. Reuss agreed with this view in the main, but thought the Gosau complex chiefly corresponded to the Turonien horizon and only partially to the

Senonien. This definition was unsatisfactory, since the French geologists assigned different limits for the Turonien and Senonien. Zittel pointed out, in a monograph on the bivalves of the Gosau strata, that the affinities were very marked with the faunas of Coquand's stages Provencien and Santonien, typically developed in Provence and the Pyrenees. The other subdivisions of the Cretaceous system also resemble the facies in the south of France, whereas the Carpathian development of the Cretaceous deposits, according to Hohenegger, Neumayr, Tietze, and other Austrian geologists, display many peculiarities, and have had to be sub-divided into a number of local groups and zones.

The faunal character of the Alpine Upper Cretaceous deposits shows a rapid variation from west to east; the Seewen limestones and marls with *Ammonites rhotomagensis*, *Holaster subglobosus*, and other Upper Cretaceous types in Switzerland, give place to the Foraminiferal limestones with *Orbitulina concava*, a characteristic Cenomanian type, in the Vorarlberg and Bavarian Alps; further east, the Upper Cretaceous deposits are represented by the Gosau strata, often distinguished as the Hippuritid or Rudistes facies, whose affinities with the Pyrenees and the Uchaux area in the western Alps is therefore a matter of special stratigraphical interest.

The occurrence of the Gosau deposits in separate crust-basins adjoining the leading east and west faults between the northern and central regions of the eastern Alps, has provided Alpine stratigraphers with some useful data regarding the regional crust-movements which are thought to have begun in the eastern Alps in Upper Cretaceous time, and to have continued intermittently during Tertiary epochs, culminating in the upheaval of the present Alpine chain.

I. *Tertiary System.*—The fundamental researches which were carried out in the beginning of the nineteenth century by Cuvier and Brongniart in the Paris basin, by D'Halloy in Belgium, and by Webster, Buckland, and Lyell in England, afforded the basis of the more detailed examination of the fossil mollusca characteristic of the successive Tertiary horizons. Brocchi, Sowerby, Lamarck, Deshayes, and Bronn demonstrated the security of the palæontological method of subdivision with the most brilliant success, and upon their results Charles Lyell established his division of the Tertiary deposits

into the Eocene, Miocene, and Pliocene formations (*ante*, p. 431)

The systematic limit between the basement beds of the Eocene and the highest horizons of the Cretaceous system had been clearly defined for Northern Europe by Brongniart and D'Omalius d'Halloy, while Buckland had defined the limit between the upper horizons of the Pliocene and the lowest Diluvial or Pleistocene deposits. On the other hand, the difficulty of determining a definite limit between Eocene and Cretaceous deposits in Alpine areas has, except in a few localities, proved insuperable to the present day.

The characteristic South European and Alpine facies of the Eocene deposits is a massive Foraminiferal limestone, composed chiefly of the remains of Nummulites (*ante*, p. 244). But in the Alps, this eminently pelagic facies is often partially or wholly replaced by a very variable group of sandstones, marls, conglomerates, shales, and clays, which is termed "Flysch," and offers palæontological difficulties on account of the rare occurrence of distinctive fossil types, and of many stratigraphical difficulties bound up with the most obscure problems in the tectonic structure of the Alps.

In 1823, Brongniart had ascertained the Tertiary age of the Nummulite formations at Ronca, Castel-Gomberto, Monte Bolca, and other localities in the Vicentine Alps; and Münster had published a list of one hundred and seventy-two species from the famous locality of Kressenberg in the Bavarian Alps, forty-two of which agreed with typical Tertiary species of Germany, France, and England, while two species showed a certain resemblance to Cretaceous species, and only a single species (*Ostrea semiplana*) was actually a Cretaceous form. Count Münster therefore concluded that the Kressenberg strata were of Tertiary age. Murchison and Sedgwick in their memoir on the eastern Alps (1830) also regarded the Kressenberg strata as Tertiary, but expressed the opinion that the Nummulite rocks near Sonthofen in Bavaria were closely united with the Cretaceous series, as that fauna appeared to contain a fair admixture of Cretaceous and Tertiary types.

The same opinion was more forcibly expressed by Dufrenoy and Élie de Beaumont in several memoirs explanatory of the geological map of France (1830-38); these authors insisted that the fauna of the Nummulite and Flysch deposits in the south of France was a mixed Eocene-Cretaceous fauna closely

related to Upper Cretaceous faunas in other French localities. They pointed out that the upheaval of the Pyrenees had taken place after the accumulation of these intermediate deposits, and therefore proposed to include them with the Cretaceous system. It was admitted, however, that the Nummulite rocks of Ronca, Monte Bolca, and a few other localities were, as Élie de Beaumont had said, of Tertiary age.

The Swiss geologists, Studer and Escher von der Linth, regarded the Nummulite deposits of Southern Europe as passage-beds between the Mesozoic and Cainozoic periods, the affinity being greater with the Cretaceous than with the Eocene faunas. Leymerie (1843) treated the Nummulite deposits in the Pyrenees as an independent formation (*Terrain epicrétacé*) between Cretaceous and Tertiary, and Tallavignes sub-divided this formation into two horizons, Iberien and Alaricien.

Deshayes and Raulin contested the supposed close affinity of the Nummulite group with the Cretaceous series, and emphasised the decided Eocene character of the Nummulite fauna. D'Archiac gave an exhaustive account of the Nummulite formation in his *Histoire des Progrès de la Géologie*, and brought forward an imposing array of arguments in favour of the Tertiary age of these deposits. Three years afterwards, in 1853, a handsomely illustrated monograph was issued under the conjoint authorship of D'Archiac and Haime. It contained a complete synopsis and description of all Nummulite species, and demonstrated that the genus Nummulites was not known to occur either in the Cretaceous deposits or in the younger Tertiary groups. This work was regarded as practically decisive, and the Nummulite formations were assigned to the Eocene period.

Meantime the Tertiary deposits of Central and Northern Europe were made the subject of many special researches. The memoirs by Galeotti (1837) and by A. Dumont (1836-41) on the Belgian development were far-reaching in their influence. Dumont distinguished (1849-52) a series of palæontological zones, and named the Belgian sub-divisions accordingly as Heersien, Landenien, Yprésien, Panisélien, Bruxellien, Laekenien, Tongrien, Rupelien, Bolderien, Diestien, Scaldisien. Sir Charles Lyell afterwards showed that the first six of Dumont's "Stages" correspond to the Lower and Middle Eocene; Tongrien and Rupelien represent Upper Eocene; Bolderien represents the Miocene; and Diestien and Scaldisien are the equivalents

of the Pliocene or English "Crag." The stratigraphy of the Tertiary deposits so ably described by Brongniart was further investigated by several eminent French geologists, a very suggestive paper on differences of facies being contributed in 1838 by C. Prévost (cf. p. 503). Hébert in 1848 threw new light upon many of the stratigraphical features, especially the structural relations at the margins of the basin.

In England, Joseph Prestwich[1] had commenced his studies of the two Tertiary basins of Hampshire and London in the year 1846. He contributed a series of memoirs to the *Journal of the Geological Society*, all of which display remarkable scientific judgment and accuracy of observation. Prestwich demonstrated for the first time the presence of Thanet Sands as a well-defined zone below the London Clay, and showed that the latter was not the equivalent of the Bracklesham and Barton strata, nor of the "Coarse limestone" of the Paris basin, but belonged to a deeper horizon. In a memoir published in 1855, Prestwich made an attempt to compare the older Tertiary groups of England with those of the Paris basin and Belgium, relying upon the results of D'Archiac and Dumont for his data regarding the Continental deposits. Both these authors had previously drawn up synchronous tables for the English and Continental developments, but the subsequent researches of Prestwich enabled him to make certain alterations from the English standpoint.

The only foreign equivalent which Prestwich could find for the *Thanet Sands* was the lower part of the Belgian Landenien (Heersien); in the Paris basin he regarded the lower glauconitic marine sands (Sables de Bracheux), the plastic clay, the lignite and the conglomerate of Meudon as equivalent of his *Woolwich Series*; true *London Clay* seemed absent in the Paris basin, but was represented in Belgium by the lower *Ypresien* of Dumont. The Lower Bracklesham or Bagshot strata were represented by the sands of Soissons, Cuise, Aizy, and Laon in the Paris basin, as well as by the upper part

[1] Sir Joseph Prestwich, born 1812 at Pensbury near London, was educated partly in England, partly in Paris, and after the completion of his studies at University College in London, he entered his father's business, from which he only retired in 1872. All his leisure was devoted to geological researches, and in 1874 he succeeded J. Phillips as Professor of Geology in Oxford. In 1888 he was President of the Fourth International Geological Congress in London; he died on the 23rd June 1896.

of the *Yprésien* and the *Panisélien* in Belgium; the Middle Bracklesham and Bagshot strata were the equivalents of the "Coarse limestone" of the Paris basin and the *Bruxellien* and *Laekenien* in Belgium. The Upper Bracklesham strata and the Barton Clay corresponded with the middle marine sand near Paris. Hébert in 1873 emended the synchronous table of Prestwich on a few points, but for the sub-division of the English Tertiary deposits the results obtained by Prestwich are the recognised standard at the present day.

The upper fluvio-marine division was described in detail by Edward Forbes in 1856, and the fossil riches of the Tertiary deposits have formed the subject of some of the greatest classics in palæontological literature. The earlier contributors to the knowledge of the English Tertiary faunas included Sir Richard Owen, Agassiz, Thomas Davidson, Edward Forbes, Milne-Edwards, Haime, and Duncan (Chap. V.).

The Miocene and Pliocene deposits of Italy were investigated by Brocchi and Bronn, and afterwards by several Italian authors and by the two Germans Hoffmann and Philippi. The *Enumeration of the Tertiary Fossils in Sicily* by Philippi appeared in 1846, and formed a valuable supplement to Deshayes' investigations, in so far as it showed that the number of living Mediterranean types represented in the Pliocene deposits of Sicily gradually increases from the lower to the upper horizons of the series, until in the highest horizons very few extinct species are present. Agassiz questioned the results obtained by Philippi, and wrote a monograph in 1845 with the special intent of proving that no living species is completely identical with the forms in Pliocene deposits, and that each individual formation contains a fauna entirely peculiar to itself. This opinion, as has been said above (p. 507), was shared in a modified measure by D'Orbigny.

A sub-division of the Tertiary deposits into four stages (*Suessonien*, *Parisien*, *Falunien*, *Subapennin*) was proposed in 1852 by D'Orbigny, and was rapidly adopted in France. The Suessonien and Parisien correspond with Lyell's Eocene formation. The Falunien is again divided into two sub-stages, the older of which (*Tongrien*) begins in the Paris basin with the Fontainebleau sandstone, and includes the fresh-water limestone and millstone quartz, while the younger horizon of Falunien comprises the *Faluns* of Touraine, of Aquitanien and Languedoc, the *Crag* of Suffolk and Antwerp, the *Molasse* and *Nagelflue*

of Switzerland, and other Miocene deposits. The Sub-Apennine stage includes, in addition to the Pliocene marine formations of Italy and the upper sands of Montpellier, a mixture of young Tertiary and diluvial deposits. D'Orbigny's classification is very unsatisfactory; it often throws together strata of quite different ages, and assumes stratigraphical limits for which there is no evidence.

In addition to Touraine, Gascony, and Turin, another district well known to the literature in connection with the Miocene strata is the Vienna basin. The first scientific observations of this area were contributed by Constant Prévost (1820) and Ami Boué (1822). The latter relied mainly on information given by Partsch and Hauer, who had been an enthusiastic collector of fossils in the localities near Vienna. In 1837, Bronn revised Hauer's collection, and by his identification of the fossils proved that the fauna was of Miocene age. In 1846, D'Orbigny published his excellent monograph on the Foraminifera of the Vienna basin, and two years later Reuss published an account of the fossil polyps.

Many geologists examined local areas and contributed sections and maps, but the first to give a clear exposition of the stratigraphical relations of the whole Vienna basin was Suess, in 1866, in a memoir entitled *Untersuchungen über den Charakter der österr. Tertiarablagerungen.* This memoir described not only the Alpine "Vienna basin," but also the deposits in the area between the Alps and the Manharts range. Suess showed that the Eocene Nummulite formation is succeeded by poorly fossiliferous marls and clays, then by the Meletta shales, which form a fairly constant band of strata in the Alps and Carpathians, in Alsace, and other localities. They are followed in the Vienna basin by the lowest Miocene strata of Molt and Horn, of Gauderndorf and Eggenburg, which are largely of fresh-water origin, and are covered by the widely-distributed "Schlier" or "Cyrena beds" of brackish-water origin. Then succeeds the richly fossiliferous Marine series, comprising sands, calcareous clays (Tegel), and limestones, passing into one another as diverse rock-facies of contemporaneous origin. The limestone facies predominates in the Leitha mountains, while the blue calcareous clays of Baden are the shallow-water equivalents of the Leitha limestones. The marine deposits were all comprised by Suess under the general term of "Mediterranean Stage."

They were shown to be followed by deposits of brackish-water origin, Cerithia sands and clays charged with shells, comprised by Suess under the general term of "Sarmatian Stage." The strata of the Sarmatian Stage are extensively distributed in the south of Europe, and the fauna had already been described by De Marny and Eichwald. At the close of the Sarmatian Stage, the deposits of the North-Alpine area and the plains are essentially fresh-water deposits, comprising the *Congeria Clays*, and the *Belvedere pebble-beds*, the latter having been deposited from running water, probably by wide river-courses pouring northward from the Alps. Suess comprised the fresh-water deposits under the name of "Pontic Stage," and identified them as the equivalent of the Pliocene formation.

A few years earlier Suess had shown from the distribution of the fossil terrestrial mammals in the various Tertiary deposits, that the older marine horizons, as well as the brackish-water "Cerithia" sands, correspond in age with the Middle Miocene in France and Switzerland (Marine molasse, fresh-water limestone of Oeningen, upper fresh-water molasse), while the upper fresh-water formations of the Vienna basin contained the fauna of the Upper Miocene deposits of Eppelsheim, Cucuron, and Pikermi. The systematic divisions established by Suess for the Austrian deposits have been verified by later investigations, and only modified in minor particulars.

The stratigraphical knowledge of the German Tertiary deposits was late in developing. There were several difficulties to contend with, the chief obstacle being the impossibility of securing a complete section from which a definite succession could be determined. This was the more unfortunate as the fossils that were found in the scattered localities seldom permitted an exact identification with the typical Eocene and Miocene forms known to the literature. The German Tertiary deposits occur in three chief districts: the North German plain, the Tertiary basin of the Rhineland, and the Swabian-Bavarian plateau with the adjacent hilly territory of the Alpine foreground.

The neighbourhood of Mainz and Alzey first attracted the interest of geologists on account of the wealth of fossils. Collini and Faujas had described some of those in the eighteenth century and in the beginning of the nineteenth century, and Dechen, Oeynhausen, and A. Boué supplied a general de-

scription of the Tertiary formations in the Rhineland. The discovery of the famous Dinotherium skull at Eppelsheim by Klipstein and Loup induced Klipstein (1836) to contribute a more careful stratigraphical account of the strata in the Mainz basin, and he paralleled the bone-bearing sands of Eppelsheim with the gypsum of Montmartre, and the limestone strata underlying the bone-bearing sands with the coarse limestone beds of Paris. In the following year, Bronn tried to prove that the Eppelsheim sands belonged to a higher horizon and were comparable with the Middle Tertiary of the Vienna basin, and he likewise assumed a Miocene age for the other sands near Alzey, "although," he said, "the characteristic species of the clays in the Vienna basin are absent."

The first accurate and detailed account of the succession of strata in the Mainz basin was given by Sandberger in 1853. He sub-divided the series into nine well-marked palæontological zones which he compared with the "stages" of Tertiary strata in France and Belgium; the zones in ascending order were: (1) Marine sands near Alzey; (2) Septarian clay and "Cyrena" marls with occurrences of brown-coal; (3) Limestone of Hockheim with land-snails; (4) "Cerithia" limestone of Flörsheim and Oppenheim; (5) "Litorella" limestone; (6) Clays and shales with brown-coal; (7) Leaf sandstone; (8) Fresh-water sands of Eppelsheim with remains of Dinotherium, Hipparion, etc.; (9) Marine sands of Cassel. Sandberger compared the Alzey sands and the Septarian clay with Dumont's *Tongrien* and *Rupelien* stages; the littoral and brackish-water deposits, from Hockheim limestone to the leaf-sandstone, he regarded as the equivalents of the marine Miocene strata in the Aquitanian and Vienna basins, and of the system *Bolderien* in Belgium; while he placed the bone-sand of Eppelsheim and the Cassel sands in Lower Pliocene, as an equivalent of the system *Diestien* in Belgium.

The sub-divisions proposed by Sandberger for the Tertiary formation in the Mainz basin have undergone very little subsequent modification. The chief alteration was made in 1854 by Hamilton, when he proved that the Hockheim limestone was not an independent horizon, but a local intercalation in the "Cerithia" strata. In 1883, Lepsius published a geographical description of the Mainz basin; and the first volume of the *Geologie von Deutschland*, by the same author (1892), affords a general survey of all the literature that has

appeared on this subject since the publication of Sandberger's memoir.

The Tertiary localities in North Germany were briefly described in the early years of the nineteenth century by several palæontologists, more particularly by Count Münster (1835). A number of the typical fossils were described by Goldfuss; Zimmermann described the Hamburg occurrences, and Boll reported on the Mecklenburg locality; but all these authors expressed themselves more or less indefinitely regarding the precise age of the Tertiary fossils and strata.

An important work on the North German Tertiary deposits was contributed in 1847 by Beyrich. This acute observer proved the identity of many of the fossils in Mark Brandenburg and in the Septarian clay of North Germany with fossils of the clays near Antwerp (*Rupelien*). Thus a definite horizon was fixed in the North German succession, and in 1853 Beyrich gave a complete account of the palæontological and lithological sequence of Tertiary deposits as an Introductory to his *Monograph of the Conchylia in the North German Tertiary Rock-Deposits*. It was made evident that the North German "Miocene" facies differed in many respects from the French and Austrian Miocene, and contained a greater number of fossil forms which had continued from older horizons.

The oldest North German Tertiary fauna was shown by Beyrich to be that of the Magdeburg sands, the equivalent of the *Lower Tongrien* in Belgium. This horizon is limited in North Germany to the area between Magdeburg and Egeln. Above it, the Septarian clay follows as the equivalent of the Belgium *Rupelien*, and Beyrich included in the same horizon the Sternberg strata and the Stettin sand. In 1853 Beyrich regarded the Tongrien and Rupelmond system, in agreement with D'Orbigny, as Lower Miocene, but in 1854 he proposed that this horizon, which was sometimes referred to Upper Eocene, sometimes to Lower Miocene, in the Paris basin and Belgian areas should be distinguished as an independent formation under the name of Oligocene. He sub-divided the new formation in three groups, the *Lower Oligocene* comprising the brown-coal deposits of the southern and eastern parts of Germany and the North German amber deposits with the rich flora worked out by Goeppert and Conwentz. To *Middle Oligocene*, Beyrich assigned the Alzey sands, the

brackish and fresh-water deposits of the Mainz basin, and the brown-coal deposits of Hesse and Rhineland. In *Upper Oligocene*, Beyrich included the Marine formations of Crefeld, Düsseldorf, Cassel, etc. These are succeeded by the typical Miocene formations of the Lower Elbe district, Holstein and Schleswig.

Beyrich's differentiation of the Oligocene formation was supported by Lyell and other eminent geologists, and proved very helpful in the systematic arrangement of the Tertiary deposits. It is noteworthy that there is no marine equivalent in Belgium, France, or England for the Upper Oligocene strata of North Germany. Probably these correspond in age with the fresh-water limestone of Beauce, which is usually classified as Lower Miocene by French geologists. Emendations in Beyrich's sub-division were made by Sandberger in 1863, when he pointed out that the "Cyrena" marls belonged to Upper Oligocene, and that the Lower Miocene should begin with the littoral and brackish-water series, the "Cerithia" and land-snail limestones, and the leaf-sands of the Münzenberg.

The Tertiary basin of the Swabian-Bavarian plateau and the neighbouring margin of the Jura mountains and the Alps is connected on the one side with the Austrian development, on the other side with the North Swiss development of the Tertiary formations, and its relations could only be properly understood after the knowledge of these formations in adjacent areas was fairly well advanced. The monograph of the Molasse deposits in Switzerland, written by Studer (1825), contains a remarkably accurate description of the different formations according to their petrographical constitution and stratigraphical position, but at the time of publication it was quite impossible to assign definite ages to the successive strata. The observations of the Bernese geologist were supplemented by the researches of Escher von der Linth, Braun, and Oswald Heer, so that Studer in 1853, in the second volume of his famous work, *Geologie der Schweiz*, was in a position to give an almost exhaustive exposition of the Swiss Tertiary deposits.

From the composition and stratigraphical position of the parti-coloured Nagelflue deposits, Studer concluded that the materials composing this conglomeratic rock and the Molasse sandstones had been derived from a marginal Alpine chain which was afterwards bent inward at the further folding and

upheaval of the Alps, and was covered by the advance of overthrust masses from the south.

Studer distinguished a *Jura* and a *Sub-Alpine* band of deposit. The former is limited to the north-western and northern parts of the Jura chain, and consists of a lower marine division with fossils which agree with those of the Mainz basin, and an upper series of fresh-water limestones and marls, whose Mammalian remains were identified by H. von Meyer as Upper Miocene. This *Jura* band of deposit, according to Studer, presents a continuation of the Tertiary basin in the Upper Rhine provinces. In the *Sub-Alpine* band the Tertiary deposits begin with *lower fresh-water* formations, which continue towards the south-west into the Rhone Valley; they consist of red marls and Molasse sandstones with beds of brown-coal, and contain an exceedingly rich flora (cf. O. Heer, p. 371). The lists of fossils which Studer enumerated prove that he comprised strata of dissimilar age within these lower deposits. The fresh-water formations are succeeded by *marine molasse*, sandstones charged with bivalve shells, and nagelflue of varied constitution. The marine fauna of this second member in the sub-Alpine band is compared by Studer with Miocene faunas, and he adds that it displays certain affinities with the Italian Pliocene. The third member is an *upper fresh-water* series, the sandy, marly, and calcareous rocks which have been so long famous for the fossils contained in them at Oeningen. These were made known by Scheuchzer, and were the subject of the admirable researches by Braun, Heer, and K. Mayer.

The identifications of the Mollusca in Studer's work were for the most part the work of K. Mayer. This indefatigable palæontologist has continued throughout his long career to describe and compare the Swiss Tertiary fossils, and to draw up synchronous tables showing their precise correspondence with the faunas of other Alpine and extra-Alpine localities. The first of these tables appeared in 1857, wherein Mayer sub-divided the Swiss series into eleven palæontological zones. The first five of these (*Garumnien*, *Suessonien*, *Londonien*, *Parisien*, and *Bartonien*) are assigned to the Eocene; the *Ligurian* stage contains the Flysch, the Upper Nummulite formations of Biarritz, the Montmartre gypsum, etc. Mayer places the Swiss representatives of *Tongrien* and *Aquitanien* in the Oligocene epoch; the *Helvetien* and *Tortonien* in the Miocene; and the *Astien* in the Pliocene epoch.

The Tertiary deposits of the Swabian plateaux were studied by Quenstedt and Probst; those in Baden and Würtemberg were elucidated by Mandelslohe, Zieten, Klein, Miller, and Schill.

The sub-Alpine band of Tertiary deposits in Bavaria comprises the Flysch deposits of Eocene and Lower Oligocene age forming hills in front of the limestone mountains. On the undulating plains stretching northward are the Oligocene brown-coal strata and the younger Tertiary deposits. Sandberger, in 1853, was the first to recognise the Oligocene age of the brackish-water strata worked for coal at Miesbach, Penzberg, and Peissenberg. He identified *Cyrena semistriata* and other typical Upper Oligocene forms in the marls, and he compared the fauna of the marine series below the productive beds with the middle Oligocene fauna of the Weinheim sands near Alzey.

Gümbel in 1861 gave a full geological and palæontological account of these Tertiary deposits in his large volume on the Bavarian Alps. A new monograph on the fauna of the South Bavarian Oligocene Molasse, by H. Wolff, places the whole of the marine and brackish-water Oligocene formations of Southern Bavaria in the Upper Oligocene horizon. Similar conclusions had been formed by Theodor Fuchs and K. Mayer regarding the age of the equivalent deposits in the sub-Alpine band of Switzerland and Austria.

From what has been said it is evident that it was no longer difficult to determine the main divisions of Tertiary strata after the true principle had been discovered of identifying the *relative* age of the component members from a comparison of the faunas contained in them with one another, and with existing genera and species. But the attempts to provide a systematic zonal sub-division of the series, capable of general application, proved fruitless. Geographical areas and biological provinces attained a very high degree of local differentiation in Europe during Tertiary epochs, so that basins of deposit which appear to have had some kind of communication, or were at least very close to one another, nevertheless exhibit marked peculiarities in the lithological and palæontological development. Each basin passed through its own history of sedimentation, in nearly all cases a most chequered history. An area that was at one time an alluvial flat would at other times be usurped by an oceanic inundation, and again become dry

land or a marginal swamp, an estuary or an inland sea. The conditions which prevailed over any one area during a definite period were often transferred during the following period to some neighbouring area, so that faunal similarities of a misleading character were bound to arise. This seems to be the explanation of the increasing difficulty that is experienced in determining the precise stratigraphical equivalents in adjoining districts; the Synchronous Tables become more and more complicated as the knowledge of stratigraphical data becomes more specialised.

The newer researches in Hungary, the Balkan lands, Greece, Roumania, Russia, India, and other parts of the world, have certainly succeeded in establishing the parallelism of the great divisions (Eocene, Oligocene, Miocene, Pliocene), but the zonal sub-divisions are extremely diverse. In North and South America, the recognition even of the main divisions is very uncertain, and it is impossible to apply any of the European zonal classifications. It would, however, occupy too much space to record the gradual progress of researches on the Tertiary formations outside Central Europe; or to indicate the debatable stratigraphical complexities that are associated with the history of crust-movements during Tertiary epochs.

J. *Quaternary Formations.*—Whereas the beginnings of the present sub-division of the Tertiary formations extend as far back as the first decades of the nineteenth century, the detailed investigation of the youngest geological system was reserved for the last three decades of the century. Buckland, in 1823, described the deposits between the Tertiary series and the sediments at present in course of formation. He regarded these post-Tertiary deposits as the discharge from a universal flood, and applied to them the name Diluvium in contradistinction to Alluvium, the name given to all modern accumulations of deposit. Lyell, in 1839, proposed to use the term Pleistocene for the Diluvium of Buckland, and in 1854 Morlot suggested Quaternary, changed by Bronn to Quartary (Quartär), a term which appears very often in the German literature, although never in the English form.

The varied constitution of the Pleistocene deposits (pebble, sand, clay, loess, bone breccias, boulder accumulations, erratic blocks, moraines) and the frequent absence of organic remains made it very difficult to determine the age of the different

members, and until about thirty years ago geologists were content to treat the series comprehensively as one group of deposit. Buckland originally defined the upper limit of the Diluvium and beginning of Alluvium as coeval with the appearance of man on the earth, but the prehistoric researches conducted in the latter half of the century showed that man had been a contemporary of some of the extinct Mammals. Palæolithic implements have afforded traces of man's existence in the latter part of the Pleistocene age. The study of the Diluvial Mammals led Lartet, in 1863, to establish three periods: the *oldest* is characterised by the predominance of *Elephas antiquus*, *Rhinoceros Mercki*, and others; the *middle* period by the Mammoth, *Rhinoceros tichorhinus*, *Ursus spelæus*, *Bison priscus;* and the *third and youngest* by the occurrence of forms still living in high latitudes, such as reindeer, musk-ox, Canadian elk, and beaver.

Research on Diluvial deposits was imbued with fresh interest when the glacial theory was established by Venetz, Charpentier, and Agassiz (1829 to 1840). It was then rendered possible, not only to understand the conditions under which the various deposits had taken origin, but also to classify the deposits according to their age as preglacial, interglacial, and post-glacial. The first researches from this standpoint were carried out in Switzerland, Scotland, and Wales (cf. p. 231). In Germany, it was not until Otto Torell had broken the spell of the Drift Theory (1875) that an active impulse was given to detailed investigations of the Pleistocene deposits on the North German plains. The results are apparent in the newer geological maps, which show the great diversity in the lithological character and age of the deposits belonging to this epoch.

The discovery of glacier scratches on the Muschelkalk of Rüdersdorf first suggested to Torell the idea that an extensive ice-sheet had covered the North German plain. German geologists have since demonstrated the occurrence of similar grooves and scratches on the rock-floor at several localities in the plain, especially in Saxony. The sands and gravels and boulder-clays have also undergone a careful exploration in the light of the glacial theory. Structures identical with the ground-moraines of recent glaciers have been recognised, and the pebbles and boulders contained in them have been examined with reference to their derivation from Scandinavia, Finland, and other northern territories. The

local moraines and the foldings and disturbances in the strata at the base of the glacial deposits are looked upon as having been produced by the pressure of the advancing masses of ice.

The effects of the erosive activity displayed by the glacial water are apparent in the giant-cauldrons, in the frequent pools, peat-bogs and circular lake-depressions, and in the long, narrow channels which extend almost parallel with one another in directions perpendicular to the southern margin of the former ice-sheet.

"While the researches between the North German plain had in view, on the one hand, to establish the chronological subdivision of the glacial deposits with the help of the fossiliferous strata, they have also been directed to explore the glacial and interglacial accumulations which bestrew the plain, and to determine the glacial system of hydrography. One of the most important results has been the proof that ridges of end-moraine extend throughout North Germany from the northern borders of Schleswig-Holstein to West and East Prussia, as well as the southern provinces of Posen and Silesia. The observation that the ground-moraine of the last era of glaciation presents the same features in front of and behind the band of end-moraines, indicates that these accumulations mark progressive stages in the retreat of the last ice-sheet, and originated during the pauses in the general movement of withdrawal. The detailed study of these hillocks and ridges of end-moraine, and the phenomena associated with them, first supplied the clue to the elucidation of the landscape features which owe their origin partly to glacial erosion, partly to glacial and fluvio-glacial deposition. By this means, also, it became possible to distinguish the different types of lakes characteristic of this extensive area of ancient glaciation.

"The glacial hydrography of the North German plain has recently had new light thrown upon it, in so far as the leading lines of ancient valleys have been brought into connection with the end-moraines of the inland ice. This has afforded an explanation of the successive origin of the great east-west valleys, each more northerly valley being younger than the next valley on the south. The ice in the last period of melting withdrew to a more northerly position, and at each pause in the withdrawal, the waters which had previously been stemmed back by the end of the ice-sheet found a new way of escape." (Wahnschaffe, *Zeitschr. d. d. geol. Ges.*, 1898.)

It is impossible to enter in detail into the important results of modern investigation of diluvial deposits, the more general aspects have been fully treated in a previous chapter (cf. pp. 220-239). Many of the questions are subjects of controversy at the present time, such as the origin of the Loess deposits, the number of distinct Ice Ages, the geographical distribution of glacial formations, and the age and significance of the various pebble, sand, and clay formations. Curiously enough, the youngest of the geological formations was the last to be generally understood, and its scientific investigation is a conspicuous feature of the present phase of progress in geology.

The question of the age of the human race, and the environment of early man, brings geology into the closest relationship with anthropology, and for the last four decades geology has done what it could to assist in the solution of the great problems associated with the beginnings of human life upon the earth's surface.

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